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The Medical Diagnostic Imaging Support (MDIS) System is a project to install Picture Archive and Communications Systems (PACS) and Teleradiology in selected U.S. Military medical treatment facilities (MTF). The MDIS specifications are based on the results of three years of university and military research and development through the Digital Imaging Network Systems (DINS) Project and the Tactical Air Command Teleradiology Project. MDIS functional specifications were compiled by a team of radiologists, physicists, clinical engineers, hospital administrators, technologists, and computer systems specialists. The contract was awarded to a joint venture between Loral and Siemens Corporations in September 1991.

Presently, Madigan Army Medical Center, Brooke Army Medical Center, and Wright-Patterson Air Force Medical Center are undergoing phased implementation of this system. Additional sites are planned for 1993-1994, including hospitals in the continental U.S., Hawaii, and Korea.

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The Medical Diagnostic Imaging Support (MDIS) System

MDIS

Imaging Excellence for Military Medicine

PACS: The MDIS Experience

RSNA '93 Today's Radiologist

Presented at the
Radiological Society of North American
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Imaging Excellence for Military Medicine

PACS: The MDIS Experience

Session Overview

Introduction....................................COL Fred Goeringer, MSCE, MBA

Reference Article: Pages 1-8
MDIS: THE NEW STANDARD IN FILMLESS IMAGING, L. CADE, R. LECKIE, F. GOERINGER, ADMINISTRATIVE RADIOLOGY, DECEMBER 1993.

History and Present Status of the Medical Diagnostic Imaging Support System...............Seong K. Mun, Ph.D.

Reference Article: Pages 9-22
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How to Set Up a PACS..........................Lt Col. Joseph Donnelly, MS

Reference Article: Pages 23-31
RATIONALE FOR A LARGE FACILITY PACS IMPLEMENTATION, J. DONNELLY, P. HINDEL, J. ANDERSON, SPIE PROCEEDINGS, VOL. 1654 , MEDICAL IMAGING VI: PACS DESIGN AND EVALUATION FEBURARY 1992.

PACS in a New Hospital: Madigan Experience..... MAJ Donald V. Smith, MD

Reference Article: Pages 32-41
DESIGN STRATEGY AND IMPLEMENTATION OF THE MEDICAL DIAGNOSTIC IMAGE SUPPORT SYSTEM AT TWO LARGE MILITARY MEDICAL CENTERS, D. SMITH, S. SMITH, F. SAULS, M. CAWTHON, R. TELEPAK, SPIE PROCEEDINGS, VOL. 1654 , MEDICAL IMAGING VI: PACS DESIGN AND EVALUATION FEBURARY 1992.

PACS in an Old Hospital: Brooke Experience.......LTC Michael Cawthon, DO

Reference Article: Pages 42-48
PACS IN AN OLD HOSPITAL: THE BROOKE EXPERIENCE, M. CAWTHON

Session Overview Continued

Filmless Radiology Department:
VA Baltimore Experience........................ Eliot L. Siegel, MD

Teleradiology.................................... Col. Harold Walgren, MD

Reference Article: 49-55
THE IDEAL TELERADIOLOGY CONFIGURATION FROM A PHYSICIAN'S PERSPECTIVE, R. LECKIE, R. DETREVILLE, D. LYCHE, G. NORTON, F. GOERINGER, SPIE PROCEEDINGS,VOL. 1654 , MEDICAL IMAGING VI: PACS DESIGN AND EVALUATION, FEBURARY 1993.

Reference Article: 56-65
EVOLUTION OF TELERADIOLOGY IN THE DEFENSE MEDICAL ESTABLISHMENT, C. WILLIS, R. DETRVILLE, R.LECKIE, G. NORTON, D. LYCHE, F. GOERINGER, J. MONVILLE, K. ENGEBRETSON, H. WALGREN, SPIE PROCEEDINGS, VOL. 1654 , MEDICAL IMAGING VI: PACS DESIGN AND EVALUATION, FEBURARY 1993.

Folder Concept for Image Organization............David Allison, MD

Medical Diagnostic Imaging Support System
Workstation.................................MAJ Robert G. Leckie, MD

Reference Article: Pages 66-79
EARLY EVALUATION OF MDIS WORKSTATIONS AT MADIGAN ARMY MEDICAL CENTER, R. LECKIE, F. GOERINGER, D. SMITH, G. BENDER, H. CHOI, D. HAYNOR, Y. KIM , SPIE PROCEEDINGS, VOL. 1897, MEDICAL IMAGING 1993: IMAGE CAPTURE, FORMATTING AND DISPLAY, FEBURARY 1993.

Quality Control................................ LTC John Weiser, Ph.D.

Reference Article: 80-89
MDIS QUALITY CONTROL PROGRAM REQUIREMENTS, LTC JOHN WEISER, CHARLES E. WILLIS

Reference Article: 90-100
ACCEPTANCE TESTING DESIGN FOR A LARGE SCALE PACS INSTALLATION, J. ROMLEIN, J. WEISER, M. SHEEHY, C. SMITH, J. DONNELLY, SPIE PROCEEDINGS, VOL. 1899 , MEDICAL IMAGING 1993: PACS DESIGN AND EVALUATION, FEBURARY 1993.

Future Implementations.........................Lt Col. Anthony Gelish, MS

Reference Article: 101-113
TELERADIOLOGY - EXPLOITING ITS PROMISE TO CREATE THE VIRTUAL REALITY DEPARTMENT, A. GELISH.

MDIS

Imaging Excellence for Military Medicine

MDIS: THE NEW STANDARD IN FILMLESS IMAGING

CPT L. D. Cade, MHS, MAJ Robert G. Leckie, M.D., and COL Fred Goeringer, MBA, MSCE

INTRODUCTION

The Medical Diagnostic Imaging Support (MDIS) System is a project to install Picture Archive and Communications Systems (PACS) and Teleradiology in selected U.S. military medical treatment facilities (MTF). The MDIS specifications are based on the results of three years of university and military research and development through the Digital Imaging Network Systems (DINS) Project and the Tactical Air Command Teleradiology Project [1]. MDIS functional specifications were compiled by a team of radiologists, physicists, clinical engineers, hospital administrators, technologists, and computer systems specialists. The contract was awarded to a joint venture between Loral and Siemens corporations in September 1991.

Presently, Madigan Army Medical Center, Brooke Army Medical Center, and Wright-Patterson Air Force Medical Center are undergoing phased implementation of this system. Additional sites are planned for 1993-94, including hospitals in the continental U.S., Hawaii, and Korea.

TECHNOLOGY CONFIGURATION

The MDIS system accomplishes four primary activities to support diagnostic medical imaging :

1. Acquire diagnostic images in a digital format and gate them into the system.
2. Communicate patient demographics and study

information into a Radiology Information system(RIS).
3. Archive and manage images and data in a database.
4. Rapidly display images and patient data on workstations.

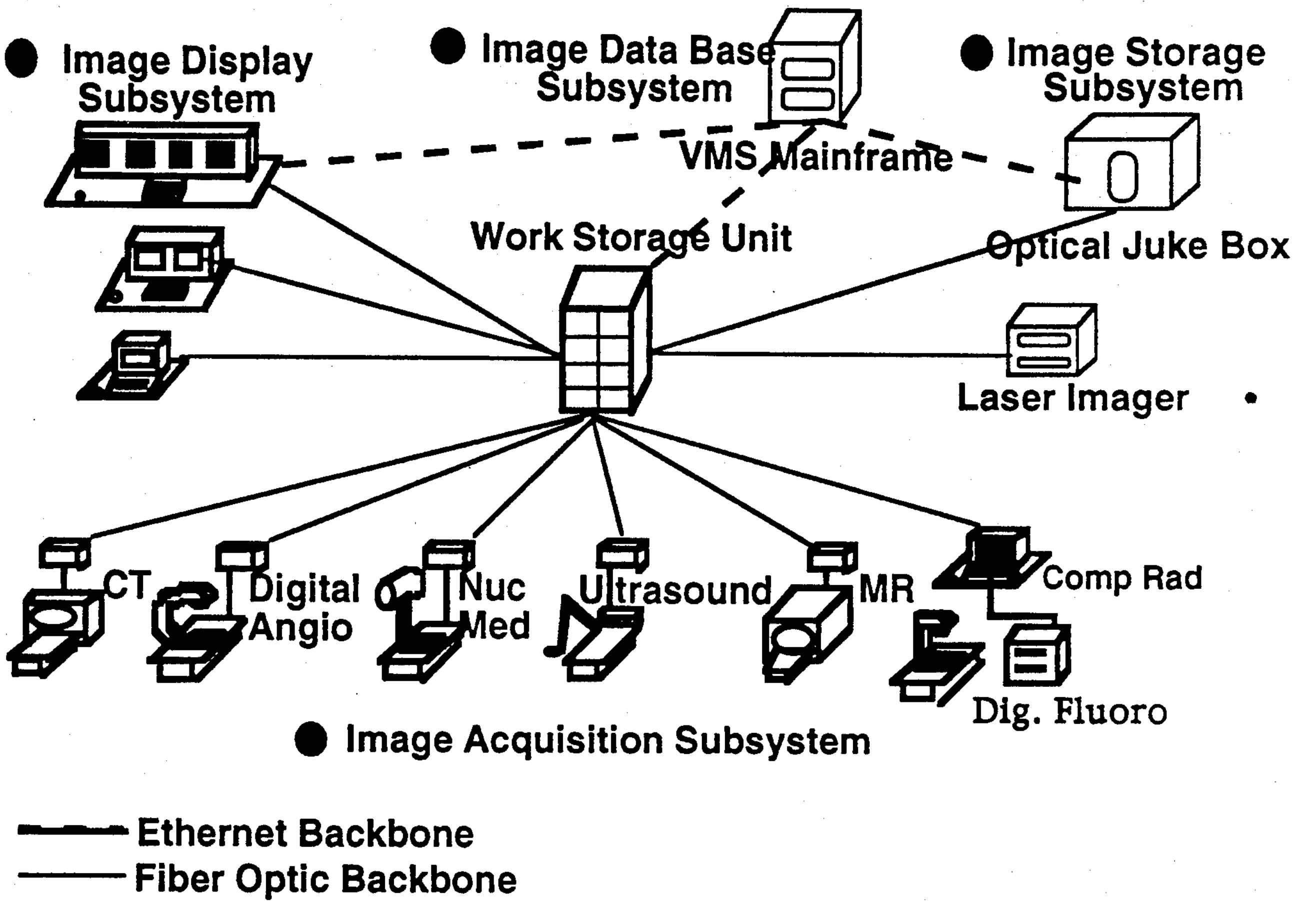
With the MDIS system, the physician uses a viewing workstation to access patient images and exam reports via a high-speed fiber optic network through a centralized Work Storage Unit (WSU) . The patient images are digitally acquired and gated into the system from the various radiology modalities present in the health care facility; these include computed radiography(CR), digital fluoroscopy and angiography, magnetic resonance imaging (MRI), computed tomography (CT), ultrasound, and nuclear medicine. Ultimately, the images are archived on optical platters within the Optical Disk Juke Box (ODJ). Conventional film/screen images coming from outside institutions can be scanned into the system using a film digitizer. See figure 1.

In lieu of conventional film and film digitizers, computed radiography (CR) technology consists of reusable phosphor imaging plates in cassettes as the image transfer medium. A CR reader extracts information from the imaging plate to produce a filmless digital image available for viewing on a workstation or on laser printed hardcopy film.

The MDIS system has a RIS built into its configuration, but will be compatible with the Department of Defense's Hospital Information System (HIS). Image data moves across the system with FDDI approaching speeds (100Mbits/sec); where as the patient demographic data is transported over Ethernet. MDIS PACS sites also function as two-way teleradiology sites and will all be connected together via the dial up switched T1 *Sprint* lines in the continental U.S.

The image storage and database subsystem maintain the information integrity of the system and insures the proper flow of images and data. The Working Storage Unit (WSU) is the "heart" of the system. The WSU acts as both a local and short term storage device. The WSU was originally designed for military image reconnaissance; as part of the defense conversion initiative, the WSU was modified to handle medical images. The WSU uses a redundant array of inexpensive disks (RAID, level 2 architecture); 40 disks (magnetic media) operate in parallel; 32 disks for a 32 bit word, 7 disks for error correction, and one disk acting as a "hot spare" (single disk failure detected and corrected without loss of operation). The

● MDIS Subsystems



WSU is designed to hold inpatients for the average length of a hospital stay, all outpatients for 48 hours, all pertinent historical images exams, and all exams not yet interpreted. Images are stored in the WSU with approximately 2.5:1 lossless compression. Image retrieval bandwidth is greater than 400 CR image equivalents per minute[2]. All of the major components are on an uninterrupted power supply.

The ODJ is the long term storage device. The ODJ holds 100 (10.2 Gbyte) 14" Write Once Read Many (WORM) optical disks. Computed radiography images are stored with 10:1 lossy compression (modified JPEG format). At 10:1 compression, each ODJ can store about one million CR images. The total number of ODJ's depends on the total long term storage requirements. The primary interpretation of an image by the radiologist is always made on the original data from the WSU before compression is applied.

The image display subsystem uses high resolution computer video terminals to display diagnostic-quality, soft-copy medical images and data. Hard copy digital versions of these same images can also be printed on single-emulsion laser film on an "as required" basis. The basic platform for the workstation is the Macintosh IIfx computer with 8 MB RAM and 80 MB internal disk drive with special image processing boards inserted by Loral and Siemens. The Macintosh-based interface is one of the keys to the user acceptance of the system; it is quite user friendly. This is critical because many of our clinicians have little computer experience. Various types of workstations are being used, based on the clinical need and cost constraints. MDIS supports two basic types of workstations: The diagnostic workstation is a high volume, primary diagnostic unit whereas the clinical workstation is a lower volume unit for clinical review of images. The diagnostic units can have either 2K (A type) or 1K (B type) resolution portrait monitors. The clinical units have only 1K (C type) resolution landscape monitors. Another difference between the diagnostic and clinical workstations are the OPUS boards with 64 MB and 32 MB of image memory respectively. The primary diagnosis for CR should be made on the 2K monitors. Lower resolution modalities such as ultrasound can be read on any of the monitors. In the radiology reading areas, diagnostic workstations with four 2K monitors are used . In general, the wards and clinics will have two 1K monitors at clinical workstations, but the entire 2K data set is available by magnifying the image and

all the image manipulation tools available on the diagnostic workstation are available on the clinical workstation.

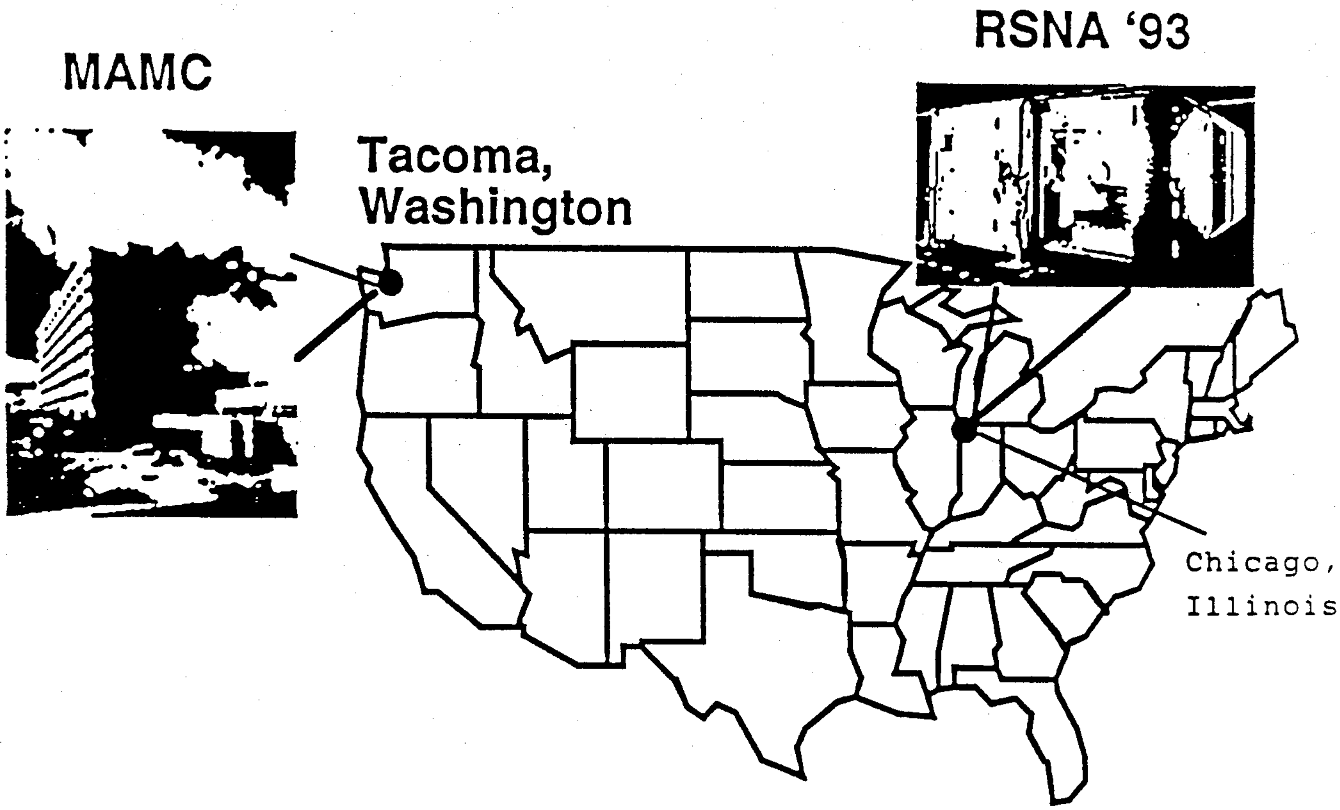
With the use of teleradiology, images are transmitted between hospitals and clinics via fixed military T1 lines(1.54Mbt/sec transmission speed), commercial dial up switched T1 lines or satellites. This allows for primary diagnosis or consultative support to remote, difficult to serve areas. All images are tied to a radiology information system with patient demographics and history. Two-way teleradiology between the hubs and spokes allows the military to balance workloads, accomplish peer review, and improve research and educational opportunities. Teleradiology is especially useful in remote areas overseas and in rural America.

The initial teleradiology sites include Luke Air Force hospital in Arizona connected to several smaller medical sites in the southwestern United States, McConnell Air Force clinic in Kansas connected to Wright Patterson hospital in Ohio, a teleradiology network linking the US Forces Korea, and a large program to connect Pacific basin sites to Tripler Army Medical Center in Hawaii. A deployable teleradiology department has been developed which will be ready to go anywhere in the world within 48 hours to support civilian disaster relief situations and the US military contingency missions. This deployable system will be showcased at the InfoRAD section of the Radiological Society of North America's annual meeting in December 1993 in Chicago. The exhibit will demonstrate our deployable two-way teleradiology isoshelter. Teleradiology images of patients x-rayed at Madigan hospital in Tacoma, Washington will be sent via the Sprint dial up switched T1 system and interpreted for primary diagnosis by radiologists at the isoshelter in Chicago. Official reports will immediately be sent back to the referring clinicians at Madigan. Clinicians at Madigan will be able to consult with the radiologists in Chicago via a teleconferencing system integrated into the isoshelter. See figure 2.

SYSTEM BENEFITS

The benefits from MDIS will be realized in cost savings as well as improvements in patient care.

Film and processing cost savings accrue as immediate near-term savings with a totally implemented filmless system.



Military Telemedicine Demonstration

Additionally, the disposal of film chemicals as hazardous waste will be eliminated, with a fully implemented system.

Contract prices for radiologists at small facilities will be reduced through the use of teleradiology. The small, remote facilities can transmit the image to a tertiary care center, rather than paying for a contract radiologist to read the image at the remote site. An economy of scale is achieved with this operating technique.

The potential for sharing resources between services using this approach is unlimited. As an example, the Air Force medical treatment facility at McChord clinic will electronically deliver medical images acquired at their facility to Radiologists at Madigan Army Medical Center.

Because of the inherent limitations with film as a hard copy media, lost film has been a chronic productivity problem in our facilities in the past. MDIS has virtually eliminated this problem with electronic acquisition of images.

File room personnel presently used to file and retrieve existing films can be eliminated or utilized elsewhere within the department. The storage space and management requirements for hard copy films will be drastically reduced as the digital film archive grows.
Patient waiting time is reduced. Traditionally, newly acquired images are sent to the fileroom to be matched up with old historical images of the specific patient. Now, the historical images are frequently on-line and available within seconds [3]; therefore, the radiologist can interpret the study immediately. Following acquisition multiple physicians have immediate access to the same image.

Probably one of the most important cost savings relates to clinician time saved by having consistent, immediate access to images and reports. Early results of the MDIS system at MAMC, indicate an increase in efficiency of the physicians translating into the ability to treat more patients.

CONCLUSIONS

The rising cost of health care in this country, to include military medicine is obvious. Through a partnership between academia, industry, and the military, MDIS has developed a PACS system that will reduce medical costs and at the same time improve patient care. Using teleradiology, expert radiologic support to remote military sites will establish a radiologic support model for civilian rural America.

The end result of all medical technology should be directed to the benefit of patients; there is no substitute for positive patient

outcome. MDIS strives to provide unequaled healthcare and establish "Filmless radiology" as the new standard.

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IMAGE MANAGEMENT AND COMMUNICATIONS (IMAC) SYSTEM TUTORIAL

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1.0 INFORMATION MANAGEMENT

A hospital generates a staggering amount of data to support many specialized patient care services. High degree of specialization requires complex collection and distribution of data to coordinate activities and to provide management support functions. In a hospital there are many redundant manual and semi automated information management activities to support the most immediate requirements in the various functional units. Current state of confusing health care information systems consists of both manual and computerized activities. A hospital information system can be grouped into six major functions;

- medical records, financial system,
- management system,
- patient information system,
- diagnostic imaging service and
- educational research support network.

Some functions overlap and others have complicated information exchanges.

In this confusing information management environment, everyone connected with health care has only a limited view of the patient care and hospital management operation. A common response to the information management problem has been a development of specialty information sub-systems for immediate and short term benefits. These sub-systems optimize the functions of the area for which they are developed with little regard to overall institutional efficiency and patient centered care process. The need for a fully integrated information system has been well known for many years. But poor connectivity in medical devices, lack of financial incentives, lack of affordable key technologies coupled and high cost of specialized products for a limited medical market have hampered any seamless system integration for the hospitals in the past.

Communication and coordination costs typically account for 25% or greater of a hospital's operating expense, and there are endless small manual tasks that everyone has to do to keep the hospital running. If one follows a typical hospital based physician making clinical rounds, one will see that the physician's activity is composed of two different steps, (a) working directly to analyze and treat the patient and (b) information gathering [1]. Historically the physician gathering information would have to go from the bedside to the chart to read the nurse's notes, to the phone to call the laboratory to gather accurate, up to date clinical laboratory values and to the radiology department to review the x-ray images with or without the radiologist. The generation of written reports is too slow, and the phones are generally inefficient for gathering information. This disseminated location of the needed information means that the physicians do not ever have all the information together at the patients bedside in a timely fashion. The physician has to depend on the notes he makes as he rounded on what each support service said, and because this is not a written report, does not know whether or not the final report might differ. At each step in gathering information, the physician would encounter the frustration of needing to wait while the information is retrieved for review. In some cases, written

reports of laboratory values and x-ray reports have been printed on the patients unit, but are often not placed in the patients chart in a timely fashion (delays of 12 to 24 hours are common) and the x-ray images are still in the Radiology Department.

Radiology services pose one of the most difficult problems of information management because they generate large amounts of data [2,3] recorded on film, which is an expensive and inflexible medium, and they must be managed rapidly and reliably for many competing users. Approximately 70% of patients coming to a hospital require some form of diagnostic examination. Efficiency and quality of radiological service are major and integral parts of patient care in a hospital. On a single day, a radiology department like Georgetown's may handle more than 300 patients and 5,000 sheets of film, including both old and new images. The management and distribution of radiology information and radiological images are responsibilities of the radiology department. Over the past two decades new imaging technologies such as MRI, CT, SPECT, and ultrasound have given the radiologist a powerful set of new diagnostic tools. Unfortunately, the quality of service in the radiology department has not experienced similar revolutionary improvements over the last decade.

In fact, the use of many varying imaging modalities has imposed additional difficulties [4] in the management of films and data because:

(a) multiple physicians need timely access to a single set of images obtained from the patient soon after image are taken,
(b) they are often produced in distant and scattered locations,
(c) it is prohibitively expensive to manage a large film library holding millions of images
(d) radiology service has become highly subspecialized causing a greater need to review multimodality images.

Films are frequently lost or unavailable when the clinician needs to see them. In a recent survey at one of our medical centers, 69% of clinicians stated that film accessibility was the greatest problem within radiology. The clinicians reported that the average time to find each study was 20 minutes and they spent in total 30 minutes to 1 hour per day locating films. In an objective study of film accessibility at the same institution, 16.5% of inpatient radiographs imaged within the preceding 8 to 48 hours could not be located, and 38% of non-chest x-ray inpatient studies could not be located. When radiological studies can not be found. physician efficiency and the quality of patient care are adversely affected. The maintenance of film libraries and film handling is labor intensive and requires large storage areas . An average 350 bed hospital may spend $1 million per year on film and chemicals. Yet, with all of its shortcomings, the traditional film based system has been the only option available.

2.0 POTENTIAL SOLUTION: IMAC

Imaging Management and Communication (IMAC) system [5,6,7], also known as a Picture Archiving and Communication System (PACS), is a network of computer-based digital imaging and information devices designed to manage medical diagnostic service. Recent advances in IMAC now offer solutions to the problems in radiology image management. A digital image can be viewed in multiple locations simultaneously. Image accountability is greatly enhanced. The problems in the past have been image quality, display speed, reliability. and user friendliness of the workstations, but these problems are gradually resolved. IMAC will significantly improve the quality, productivity, and efficiency of radiology service by

a. offering immediate access to images to any users, any where at any time,
b. eliminating needs for many redundant manual activities,
c. converting film library to an electronic data base, and
d. providing radiological reports to referring physicians in a timely manner.

An IMAC network system consists of 5 major subsystems:

a.Image Acquisition Subsystem
b.ImageDisplay and Workstation Subsystem
c.Image and Text Database and Storage
d.Interface to Radiology Information System
e. Communications Network Subsystem

The image acquisition subsystem includes digital radiography systems, film digitizers, and interfaces to standard digital imaging devices. The image output and display subsystem includes hard copy laser printers and image display workstations for primary image interpretation and secondary clinical review. The image database and storage subsystem require a database management system for image and data storage. An interface to radiology system is an essential part of an IMAC network. The communication subsystem connects all of the components and moves images and text data from one unit to another.

2.1 IMAGE ACQUISITION SUBSYSTEM

Many medical imaging systems such as computed tomography (CT), nuclear magnetic imaging (MRI), single photon emission computed tomography (SPECT), and positron emission tomography (PET) are already in digital form. These digital images constitute approximately 30 % of the total volume of images produced in a radiology department. The remaining 70 % of images including conventional x-ray film of the chest, skeleton, abdomen and GI tract. Unless one develops a method of handling these conventional film images, global improvement in productivity in image management and radiology service throughout a hospital cannot be achieved.

Currently, there are two methods of producing digital information representing these conventional analog images for IMAC: film digitizers [8] that scan the conventional films, and computed radiography (CR) that captures x-ray images using storage phosphor plate [9,10,11,12] that is subsequently scanned by a laser beam.

A laser film digitizer functions by scanning a conventional x-ray film image with a focused laser beam and recording the amount of light transmitted by the film. Film digitizers are indirect means of acquiring digital images because they depend on a conventional x-ray film image for primary imaging. Film digitizers also depend on the transmission of light by the film, causing the reversal of the signal to noise characteristics. Dark areas of film represents capture of more x-ray photons by the film, meaning less quantum noise, but when the film is digitized, small number of photon get through the darker area, causing increase in random noise within the darker region of the image.

The computed radiography (CR.) enables the direct acquisition of radiological images. Computed radiography system uses photostimulable luminescence as a primary image receptor. The computed radiography systems utilize a cassette similar to a conventional radiography cassette except for the fact that the film/screen system of conventional radiography has been replaced by the reusable phosphor imaging plate. The cassette is similar to that used in conventional radiography so that no retrofitting of existing x-ray equipment or exam rooms is necessary. The exposure latitude of the phosphor plate is extremely wide when compared to that of film/screen systems. The phosphor plate's wide exposure latitude also makes CR ideal for portable chest exams in the intensive care unit (ICU) environment [13,14], which has traditionally suffered from under and overexposure and a resultant relatively high amount of retakes. Recently, a number of institutions have converted most of conventional radiography to CR devices.

2.2 IMAGE DISPLAY AND OUTPUT

In a filmless imaging environment, diagnostic images are viewed on CRT monitors driven by various workstations. At least three types of workstations are required; the diagnostic reporting station. the review station. and the special application workstations. The distinctions are made based on the use, the performance requirements, and the cost of the system. These distinctions are however becoming blurred as image display and processing technology is improving rapidly.

The diagnostic reporting station [15,16] is primarily for radiologists and a few specialists to read new and previous exam images and generate diagnostic reports. This workstation should support simultaneous viewing of at least four 2,000 x 2,500 images with 10 bits of dynamic range on large monochromatic non-interlaced screens. Some MR and CT images have 12 or 16 bit data and the display processor should preserve the full dynamic range for processing and

computation. It should be noted that image display (CRT) can display no more than 8 bits of gray scale. The station should have a set of highly interactive routines for image presentation and processing. The system should also have an integrated direct diagnostic report generating capability. This will make reports quickly available for distribution to referring physicians. Two key requirement for the workstation is display speed and sequence of image display. On a single day during a diagnostic reading session, a radiologist needs to view 200-300 sheets of images (2,000 x 2,500 x 10 bits per image). In the case of MRI and CT, it is common for a radiologists to view more than 1,000 frames (256 x 256 x 12/16 bits per image) during a daily reading session. Display speed of 2 seconds per large image is called for currently. Every radiologist has a certain way of displaying multiple images of same studies obtained at different times and multiple images of different imaging systems. The relative location and order of display of particular images with respect to other images on multiple screen workstation must be predictable and logical to the radiologists.

The review workstation is primarily for referring physicians and for consultations rather than primary diagnostic reporting. It supports high resolution (1000 x 1200) displays with the ability to access and edit reports. These workstations can be located throughout the hospital and within the radiology department.

The number of display screens and images desired for simultaneous viewing is an important feature for a diagnostic reporting workstation. Currently 40-100 images are presented to the radiologist simultaneously in the case of MR or CT and 4-8 images for chest and bone studies. It is essential for the diagnostic reporting station to provide rapid access and display of images.

2.3 STORAGE AND SYSTEM INTEGRATION

Depending on system architecture, image storage [17,18] may be distributed at several hardware components on the network. Storage devices could include magnetic tape drives, magnetic disk drives, as well as erasable and non-erasable optical drives and related magnetic and optical juke boxes and optical tape devices as they apply to medical imaging.

Images and related information that should be in the short-term storage are (a.) exams that are newly acquired in the past 48 hours, (b.) exams awaiting primary interpretation (c.) exams acquired in a period equal to the facility's average length-of-stay for inpatients, (d.) selected historical exams are needed at clinical areas according to a daily clinic appointment schedule, and (e.) selected supporting historical exams of patients who have had new image exams.

The long-term archive should be capable of storing the current year plus 4 additional years of imaging exams for a total of 5 years of imaging exams. In the case of Georgetown University, we generate approximately 5 Terabytes per year, excluding mammography. Additionally, there are certain instances where exams must be retained more than 5 years- e.g., pediatric images must be retained until a patient's 21st birthday and some mammography exams must be retained for the life of the patient.

External communication requirement will depend on the work load and work pattern of radiology service. For a small scale operations ethernet or 19.2 Kbps modems are sufficient. As data volume increases, higher speed such as 100 Mbps or T-1 lines will be needed.

System integration in IMAC technology shares many of the generic problems in computer technology. Most of imaging devices of today are not designed to support network operations and in some cases certain manufacturers are reluctant to provide proper interface capabilities to move images. Efforts are underway under the auspices of American College of Radiology and National Electrical Manufacturers Association to develop an interface standard known as ACR/NEMA interface standard [19] which is also known as DICOM interface. A growing number of manufacturers and organizations are adopting the standard.

Data compression [20,21,22,23] is an important topic in radiology for it can improve network performance and reduce the data storage requirement. Many physicians feel that any lossy compression may contribute to erroneous diagnosis, while many scientific studies show that there is not any statistically significant difference in diagnosis even when the images have been subjected to 15:1 compression.

2.4 RADIOLOGY INFORMATION SYSTEM

The IMAC system requires several capabilities in addition to the imaging functionality. These include entry and use of patient demographic data, order entry functions, and results reporting that are traditionally handled by radiology information system (RIS). Interface of IMAC with RIS [24, 25] avoids redundant manual entry of common data elements in the RIS and the IMAC databases for routine clinical operations at patient registration points, image acquisition sites, or display workstations. In some IMAC networks, an auto routing of images to workstations may be desirable to avoid data traffic bottleneck. A radiology exam order entered in the RIS for a procedure or procedures could prompt the IMAC image database to do 'auto-routing'. The RIS information can trigger the image database to do auto-routing of (a) exam orders, (b) pre-interpreted image exams (c) post-interpreted archived image exams and (d) radiographic reports, across the IMAC network. This auto-routing may be targeted to specific acquisition and display devices, both in and outside of the radiology department according to site-unique, site definable/modifiable algorithms. Traditionally, the reports are usually generated in RIS.

To referring physicians, who are the primary users of radiology service on behalf of their patients, the availability of diagnostic reports is often more important than the images by themselves. Missing reports, unsigned reports and separation of reports from the images are major problems today. Integration of convenient and efficient reporting capabilities with the IMAC workstation can reduce the frequency of occurrence of these problems. Integration of the reporting systems and the workstation will transform the IMAC from an image shuttling system to a complete diagnostic decision support system.

2.5 TELECOMMUNICATION

An IMAC network within a hospital can be connected to a smaller remote site or to another hospital for long distance teleradiology service. This communication can be achieved using dedicated T-1 lines, dial-up fractional lines and others service that local communication companies can offer. In some case this can also be a higher speed of 1 Gbits per second.

3.0 A LARGE SCALE IMAC PROJECT: MEDICAL DIAGNOSTIC IMAGING SUPPORT (MDIS) PROJECT

There is an increasing number of hopital-wide IMAC projects around the world, but one project of the US Department of Defence is used as an example of advances in IMAC technology and implementation. The Medical Diagnostic Imaging Support (MDIS) System is a large PACS and teleradiology project for the U.S. military [26,27]. The contract was awarded to a joint venture between Loral and Siemens in late 1991. Presently, Madigan Army Medical Center, Brooke Army Medical Center, and Wright-Patterson Air Force Medical Center are undergoing phased implementation of this system. Several other sites are planned for 1993-94, including military medical treatment facilities in the continental U.S., Hawaii, Korea, Panama, and the Azores off the coast of Portugal. Similar technologies are being installed at Hammersmith Medical Center in London, UK and Baltimore Veterans Medical Center in Maryland.

3.1 MADIGAN MDIS NETWORK OVERVIEW

The new Madigan Army Medical Center opened its doors in the Spring of 1992. Madigan is a 1.2 million square foot, 416 bed facility in Tacoma. Washington. Approximately 500 physicians representing nearly all subspecialties work at this tertiary care medical center and see over one million outpatient visits per year. The Department of Radiology with 12 staff and 18 residents, does over 160,000 radiological exams per year.

The initial phase of MDIS at Madigan includes computed radiography for all plain x-rays except mammography and scoliosis series, a 20 Gbyte Working Storage Unit (WSU), a 100 platter (1 Tbyte) Optical Disk Jukebox (ODJ), and nine workstations. The computed radiography images are processed by two Siemens Digiscan 7000 and three Fuji AC1 plus readers. Third generation Fuji imaging plates are used. The

Working Storage Unit (WSU) uses a redundant array of inexpensive disks (RAID, level 2 architecture). It functions as the local and short term storage using 40 disks (magnetic media) operating in parallel; 32 disks for a 32 bit word, 7 disks for error correction. and one disk acting as a "hot spare" (single disk failure detected and corrected without loss of operation). The WSU is designed to hold inpatients for the average length of a hospital stay (4.5 days for Madigan), all outpatients for 48 hours, all exams not yet interpreted, and pertinent historical images. Images will be stored in the WSU with 2:1 lossless compression(currently no compression is used on the WSU). Image retrieval bandwidth is greater than 400 CR image equivalents per minute. The full implementation WSU will have five times the present storage capacity(by doubling the capacity and implementing 2.5:1 compression). The WSU is connected to the workstations by a fiber optic network in a modified star topology. Image data moves with FDDI- like speeds (100 Mbits/sec). Images are transferred at the earliest opportunity from the WSU to the ODJ. The ODJ holds 100 (10 Gbyte)WORM 14" optical disks. Computed radiography images are stored with 10:1 lossy compression (modified JPEG format). The final phase calls for two ODJs which will be able to store about 3 years of images on line. Presently, as part of the phased implementation, all computed radiology (CR) and fluoroscopy images are stored both softcopy and hardcopy (laser printed film) with the exception of GI barium cases which are softcopy only. CT and MRI images are expected to be available on the PACS in April of 1993. Nuclear medicine, ultrasound, angiography, and radiation therapy will be connected to the system in late 1993. A total of 9 workstations are presently in service: one each in the orthopedics clinic, the emergency room (ER), and the intensive care unit (ICU), with the rest in the radiology department. In the Summer/Fall of 1993 an additional 116 workstations will be placed throughout the clinics and wards of the hospital. Following this installation, Madigan will begin to go almost entirely filmless .

Various types of workstations are being used based on the clinical need and cost constraints. MDIS supports two basic types of workstations. a standardized and an optimized. The standardized workstation is a high volume, primary diagnostic unit whereas the optimized workstation is a lower volume unit for clinical review of images. The standardized units can have either 2K (A type) or 1K (B type) display matrix portrait monitors. The optimized units have only 1K (C type) display matrix landscape monitors. The primary diagnosis for CR are made on the 2K monitors. Lower resolution modalities such as ultrasound can be read on any of the monitors. In the radiology primary reading areas standardized workstations with four 2K monitors are used. In general, the wards and clinics will have two 1K monitors at optimized workstations, but the entire 2K data set is available at these workstations by magnifying the image either by a zoom function or use of the "magic glass" tool in the region of interest. All the workstations have the same basic image manipulation functions. The primary advantage of the four monitor workstations over the two monitor workstations is convenience and image display throughput. Comparing multiple images can be done with two monitors, but significantly more image manipulation is necessary. Initially, we considered eight monitor workstations (4 on top. 4 on the bottom simulating a conventional alternator board); with our present experience we do not feel that the added benefit would justify the costs. Even large barium series can be comfortably reviewed on the four monitor workstations. The basic platform for the workstation is the Macintosh IIfx computer with 8 MB RAM and 80 MB internal disc dive. A key feature of the system is the connection between the workstation, database, and WSU. The workstation queries the database via an Ethernet line. The database provides the workstation with the necessary information and access rights to retrieve image data from the WSU. The WSU transmits images to the workstation via a direct fiber optic link to the image memory of the OPUS board, with as many images as possible stored on the OPUS board. Once full, the system automatically pages images in from the WSU.

3.2 PRIMARY DIAGNOSIS IN RADIOLOGY

There are two primary ways to view the images, the traditional or "diagnostic " mode in which images are side by side and the "cine"

mode in which all the images in the series are stacked one behind the other. The latter mode is especially helpful in axial CT or MR series when following a structure in the cranial to caudal direction. It is also useful for looking at multiple images of the same anatomic region over a short period of time such as a barium swallow. Within the cine mode, the images can be viewed as a movie or image by image based on the users desires.

The following image manipulation tools [28] are available on the system: window/ level, magnify, pan, region of interest signal measurement, distance and area measurement, annotate, flip/ rotate, equalization function, the" magic glass", and inverted gray scale. The window/ level can be changed simultaneously with the mouse or the user can set his own pre-selected window/ level values. A special function called the magic glass is extremely useful. This gives the user a window box in which either magnification of the image by a factor of two, inversion of the gray scale, or equalization of the image within the box can be done without changing the rest of the image. The user can rapidly scan the study by moving the box around the image. By depressing the apple key at the same time, he can also change the window/level within the box. By depressing the option key he can continue to magnify the image. Depressing the control key changes the size of the box. The image manipulation within the box occurs instantaneously. We have found this function to be very useful.

The invert gray scale is helpful in locating the tips of tubes and lines. It also appears to increase the conspicuity of polyps in barium GI studies, and certain bony structures such as sub diaphragmatic ribs on a chest x-ray. The workstation allows the user to hide patient images (for QC of images not acceptable to be presented to the radiologists and clinicians), demographics (useful for patient confidentiality issues).

3.3 RIS INTERFACE

The radiology information system (RIS) is an integral part of the MDIS workstation. Once the user selects a patient's study within a work list, the radiological request and dictated report (if completed) automatically show up on the bottom of the screen. Therefore, the patient's clinical history. Radiological images, and dictated report are present together on the workstation monitor for the radiologist or clinician to see. An internal review performed at Madigan before installing the MDIS system showed that of randomly selected radiological cases, the patient's dictated report, images or both could not be found in the file room in 50% of the cases. The MDIS system is expected to virtually eliminate this problem. The Composite Health Care system (CHCS), the Department of Defense's hospital information system(HIS), is expected in the near future. The MDIS system will be (by contract) compatible with CHCS.

Usually the radiologist dictates a report to a transcriptionist, but if he desires, he can type in the report himself. Standardized radiology reports are available on pull-down menus. These standardized reports are used almost exclusively on the Gastro-intestinal (GI) service ,frequently with slight modifications, such that final reports are now often available to the clinician the same day as the study was done.

3.4 IMAGE ACCOUNTABILITY AND SYSTEM RELABILITY

The failure of a conventional film based system on image accountability is one of the primary reasons to convert to a PACS environment. It has been stated that PACS will result in no loss of images. Some images are still misplaced, but this time electronically. During summer of 1992, we reviewed 150 studies done in the first 3 months at Madigan after moving into the new hospital. Hardcopy laser printed images could not be found in 20% of the cases. Surprisingly, 10% of the cases could not be found on the MDIS system. Closer examination showed that some studies were located under a different folder heading, e.g., a chest x-ray listed as an abdomen; other cases coming through the emergency room were initially listed as "John Doe" and never converted to the proper name in the database. Finally, in the first 3 months of operation, there were a significant number of "bugs" to work out of the system. Actions have been taken to address these problems. A follow-up study was done in which a week (early November of 1992) was randomly selected to review image accountability. The image in

question could be found in its exact heading or similar title (e.g., toe under foot heading) in greater than 98% of cases. In some cases, the patient's name was incorrect, in others the image was under the wrong heading as was the case with initial operation of the MDIS system at Madigan. This was most common when multiple studies were done on the same patient especially in an emergency situation- the radiology technologist only made up a single bar code and put all the images under this heading. We are presently educating our technologists on the importance of using a bar code for each study and working with the vendors to design a tool to transfer images to the proper heading.

A high level of reliability is critical to the success of a PACS. Our contract calls for 98% system up time. Any down time of the VAX, WSU or ODJ can affect the user at the workstation. Over the initial 10 months, the MDIS system has been up and running 98.8% of the time. Presently one of the major causes of down time is related to the air conditioning system . We have an Uninterrupted Power Supply (UPS) but no back-up air conditioning system in the computer room exists presently. The equipment in the computer room generates a significant amount of heat. The central hospital air conditioner has failed several times. In each case, the system has to be brought down due to the danger of overheating. We are presently working on acquiring a back-up air cooling source to resolve the issue. Excluding air conditioning related problems. the system has been operational 99.7% of the time. During the down times, the system is in the "fail over "mode. Hardcopy laser printed images are produced for immediate needs and they are digitized back into the system.

3.5 IMAGE DISPLAY SPEED

Image display speed on the workstation is primarily related to the location of the image data at the time of the request. In general, if the image is still on the WSU, it takes consistently 5-6 seconds to display the image on the monitor. The vendors are working to reduce the time to less than 2 seconds. If the image is archived on the ODJ, the average time to display is 1.8 minutes presently. The time to display an image from the ODJ is variable. Several factors influence this display speed. Only one study can be fetched at a time, therefore the time depends on the number of studies that other users are seeking at that time. Presently if the ODJ is in the middle of archiving another case, it must complete the task before retrieving the study requested.

The time to paint images on the screen depends on the size of image data set, screens and type of workstation. The following is an example of the screen paint speed. Given a 50 image CT study on a standardized four screen 2K workstation in the 12 image on 1 page format (12:1), it takes on average 57 seconds to paint the entire study. In practice, this number is less important because the clinician can start his evaluation of the study once the first screen is painted (about 5 -6 seconds). To convert this study to the stacked cine mode takes 7.9 seconds, and returning to the 12:1 format takes 15 seconds. To page down to the next set of images (display images of the study that did not fit on the first four screens) takes 2.5 seconds. Paging up takes 1.8 seconds. These times are expected to improve on the diagnostic workstations with improved new imaging boards.

3.6 READING TIMES

As opposed to a clinician that may review a few imaging studies a day, the radiologist spends the majority of his day looking at images and making diagnoses. Even a small percent change in the rate at which he reviews images, can therefore have a major effect on his overall work efficiency. We tested the time it took 3 board certified radiologists to review and dictate the same 30 CR imaging studies. Each reader reviewed the 30 cases both softcopy on a standardized 2K four monitor workstation and hardcopy as laser printed images. The soft and hardcopy sessions were separated by at least 3 weeks in 2 of 3 cases. The 30 cases were randomly selected outpatient imaging studies composed of 10 bone, 10 supine and upright abdomen, and 10 single view chest x-rays. The order of reading (soft copy images first vs. hard copy images first)was varied. No old comparison images were used. The hardcopy images were separated out and placed on top of the master jacket. Timing measurements began with the radiologist reaching for the images placed beside him and ended after a handwritten report was generated and the study placed into the

master jacket. The softcopy cases were stored on the WSU in a random order such that the radiologist had to type in the patient's last name to retrieve the images.

Overall, reading images on the hardcopy was 35% faster than the softcopy images. Yet this varied significantly between the experience of the reader and even the type of study being read. The experienced reader was only 9% faster hardcopy than softcopy. The two less experienced readers actually began reading softcopy images faster as the test progressed - the first reader went from reading hardcopy 50% faster to only 36% faster; the second reader went from 45% to 24% faster on the hardcopy. This probably reflects the learning curve involved in reading soft copy. Several new software features have not yet been implemented on the MDIS workstations that will significantly speed up the softcopy reading times. We believe these features will make softcopy reading competitive with the traditional film environment. With conventional film the image cannot be manipulated, whereas on the workstation with several easily accessible imaging tools at the radiologist's disposal, an attempt can be made to extract additional information that was previously unavailable. The user now balances time with depth of investigation of the image.

3.7 IMAGE QUALITY

Presently all CR images [29]are available both on hardcopy and softcopy. After greater than 10 months of clinical use and more than 100,000 CR studies. to our knowledge, no cases have been documented in which a finding was noted on the hardcopy, but not on the softcopy image. On the other hand, several clinical findings are routinely noted on the workstation that are inconspicuous or absent on the hardcopy images. Another advantage of softcopy with CR images is that the Fuji contrast imaging algorithms (G factors) have no effect one image quality on display workstations. In some cases, we had problems with the original Fuji algorithms (e.g. feet, barium studies) giving suboptimal hardcopy images, but on the monitor they look fine. At this time, edge enhancement/unsharp masking is not available at the workstation. This is planned to be incorporated in a future release. Simple pixel replication is used on the system instead of interpolated zoom. This causes the CT and MR images to look pixelly when viewed on the workstation in the traditional 12:1 format. Primary diagnosis is only made on images with lossless compression. We are using 10:1 lossy compression on CR images after a primary diagnosis has been made and before archiving the images in the ODJ. We believe that with 10:1 compression clinically relevant information is not lost ; a large ROC study will soon begin at Madigan.

3.8 REFERRING PHYSICIANS

A recent survey of 58 surgeons, internists, and pediatricians at Madigan revealed that 100% believe the MDIS system is useful to them, 100% believe it saves them time, and more than 98% believe it helps to improve patient care. As mentioned earlier, many clinicians have learned how to use the system before they received formal training. Clinicians now go to the workstations in radiology routinely to look for imaging studies instead of going to the file room. It is clear that the place where MDIS is most appreciated is on the wards and clinics. The orthopedic department has a workstation in its clinic. In the past. patients that arrived for follow up appointments for fractures without their old x-ray films would either be canceled and told to return with the films or retake x-rays. In their busy clinic, the orthopedic surgeon could not afford the time to go down to radiology and try to find the old film. Now he can just pull the patient's old study up on the workstation in his clinic, thus saving time, money, and/or unnecessary additional radiation exposure to the patient.

In specialty areas such as the ICU, traditionally an area first targeted by PACS [12,13], the advantages are more subtle. The ICU chest x-ray hardcopy images are maintained on a large dedicated alternator board in radiology. The images are sent straight to the board, thus bypassing the file room. The ICU team comes to radiology each morning to review the morning chest x-rays. Therefore, some of the traditional problems of the film based system are not a problem in this environment. The advantage comes in the middle of the night or day when a patient is in acute distress and time is critical. The clinician can view the patient's images in

this case without leaving the intensive care unit. It is in this scenario the workstation in the ICU demonstrates its usefulness.

The GI radiology service is completely filmless now. The radiology technologists on GI anecdotally believe being filmless saves them time. We are planning timing trials to verify this claim. The radiology residents and staff also prefer the filmless environment in GI. The imaging tools, such as the magic glass, inverted gray scale and magnification, seem to be especially useful on the GI service. The general feeling of the radiologists at Madigan is that the system has great potential, but better image navigation software would enhance the value of PACS significantly. PACS is (and will remain so in the near future) most beneficial to the clinicians, not to the radiologists. Having workstations on the wards and clinics will be the pathway by which PACS will succeed and be widely accepted in the field of medicine.

3.9 FUTURE DEVELOPMENTS AT MADIGAN

In the following months, the remaining imaging modalities such as ultrasound, nuclear medicine, angiography, and radiation therapy will be integrated into the system. The remaining 116 workstations will be placed throughout the hospital. The Hospital Information System for the military (CHCS) is expected to be installed and MDIS will be interfaced with this system. Pre-fetch algorithms to bring images from the ODJ to the WSU and a larger storage capacity at the WSU will improve image retrieval times. Special clinical sub-folders are being designed to allow key images from different sub-folders to be located together, e.g., a patient with a lung mass might have a folder with his previous two chest x-rays, a chest CT, and a bone scan in it. This would allow the clinicians more rapid access to the studies they are interested in and also decrease the overall amount of image data passing through the network since the selected images are fetched instead of all of the patient's images. A gateway is being developed to provide for teleradiology [30] connections to other hospitals and clinics within Madigan's referral region.

4.0 NEW IMAC PROJECT AT GEORGETOWN UNIVERSITY

Georgetown University has installed an IMAC network based on AT & T's CommView System in 1988. The primary network topology used in the system is a star based on 40 Mbytes per second optical fiber. The central data management system (DMS) is connected to: (a) acquisition modules (AM) which collect images from imaging devices, (b) high-speed workstations located throughout the hospital, (c) an archival jukebox of 89 Optical Platters, (d) an interface to a Radiology Information System (RIS) through a PC, (e) gateways that support specialty image processing for research workstations on an Ethernet.

In the spring of 1992, the scope of IMAC network at Georgetown has been reduced to support primarily intensive care services and ultrasound service. Provision of images to intensive care units do not involve a large data volume and the current system performs well. Service to CT and MRI have been dropped. Since the manufacturer of Georgetown IMAC network, AT&T, has suspended all development, the performance of workstation and data base has never reached an acceptable level in terms of display speed, user interface and data query capability to support routine high volume diagnosis required for radiology.

A new IMAC project is underway at Georgetown. Georgetown has developed a 5 year plan for a paperless and filmless hospital with a short term objective of a filmless radiology service within the next 3 years. The following highlights the 5 year program.

Year 1: all inpatient, emergency room and outpatient chest and bone images will be obtained in digital form. There will be dedicated digital imagers in the ICUs. Day to day operations of general radiology will depend wholly on the IMAC network, eliminating the need for hard copy film images. Approximately 70% of our radiological workload (120,000 cases per year) is conventional radiography. We are targeting this area because the success in general radiology will have the most positive impact in convincing skeptics that the IMAC system is indeed clinically preferred.

Year 2: MRI, ultrasound, angiographic

images, and nuclear radiology images will be placed on the network. The number of workstations will be expanded to those areas that require frequent access to MRI and nuclear images. Technical collaboration with the patient care information system (PCIS) will begin. We will begin experiments with pathology images to support telemedicine concept.

Year 3: CT and the remainder of the radiology imaging systems will be interfaced to the IMAC network. Georgetown has the first state-of-the-art spiral scanning CT from GE. We are negotiating an interface with GE's CT group and they will be placed on the network. Radiology, pathology and cardiology images and related text data will be available at selected workstations in the hospital and selected outpatient sites.

Year 4: A commur˙cation and computer infrastructure will be in place for a workstation that can access hospital information, patient care information and radiology images. Infrastructure for computer aided diagnosis and expert system support will be ready for implementation throughout the hospital. Medical records and other hospital system will be up-graded to support paperless operations in the following year.

The 5th year will be devoted mainly to completing a hospital-wide use of paper independent and film independent technologies. At the end of year 5, the evaluation of the effectiveness, advantages and problems of this totally digital radiology, pathology, and hospital information system will be completed.

5.0 CONCLUSION AND FUTURE ACTIVITIES

An information management project such as IMAC brings out many deficiencies in the current system. Many of these old shortcomings which may not be directly related to imaging must be addressed to take full advantage of communication and management technologies. Past experience suggests that for long term success the entire process of radiology operations including communication and management infrastructure must be addressed so that one of two bottlenecks do not bring down the entire network and limit the utility of the new capabilities.

Seen from the patient care and hospital operational perspective IMAC technology together with imaging technology must offer clear advantages for the radiology service in three general areas; (a) new digital imaging modalities to reduce the dependence on film, (b) significant operational improvements and (c) new diagnostic information.

The introduction of CR technology [29,31] has been a significant factor in IMAC, and more manufacturers are offering competitive capabilities. While it is clear that current technology can replace most of the film imaging for chest and bone, new higher resolution capabilities may be required for hands and premature infants. A number of new x-ray detectors have been studied to develop new digital radiography systems. Mammography is an important part of radiology service, but a digital mammography system is yet to be developed. A great deal of activities are underway to develop a digital mammography system [32] that requires much higher resolution (50 micro per pixel) than chest imaging.

Operationally, image data base is a subset of radiology information system (RIS). Integration of IMAC network to RIS is an essential part of IMAC technology. Collaboration between IMAC developer and RIS developers is needed in the future. As discussed earlier the imaging system of the future must have more efficient and less costly interface capabilities based on a common standard.

In the past some of us viewed IMAC as a means to move images rapidly, but as image processing capabilities become faster and less expensive, IMAC should be more than an image management system. The network should provide additional capabilities that can improve the quality of diagnosis. This can be achieved by integration of computer aided diagnosis, tissue characterization, 3-dimensional image display and multimedia data presentation.

Two types of changes [33] that will result from new information management technology such as IMAC; changes in work habits and changes in power and control. The changes in work habits will involve changes in the location and techniques used for viewing images and in the manner in which the radiologist provides radiology consultations. Fewer will be in the x-ray department, more will involve phone consultations with both parties looking at the

image simultaneously.

Everyone in patient care recognizes the problems faced by radiology services, especially in film and report management, but it is difficult to agree on which party should address the problems. With the current file system, the images are controlled by the radiology department and the problems related to them are the responsibility of the radiologist and radiology administrator; there is power in having that control. With IMAC, the images are available throughout the hospital, and therefore the power that comes from control is decreased. Radiologists will be losing some of their control over the images. In order to maintain their effective consultative relationship and their ability to bill for services they will have to work smarter so that the reports are available with the images.

In most cases, an IMAC system does not develop new sources of revenue. One of the major challenges for any hospital considering an IMAC is justifying its financing. If a technology does not result in new income, then its costs must be justified by cost savings either of supplies or in personnel. If one does not create a film image, then there are substantial savings to be made in not using film, film jackets and developer. At Georgetown, the annual film costs are close to $1,000,000. While it may be possible to decrease the number of film librarians after a transition period, it is likely that IMAC will result in new tasks for an equivalent number of workers. The major personnel saving that can result from an IMAC is in its saving physician time, mainly the time of the primary physician and clinical consultants. In Japan and France, financial incentives for IMAC may come from high reimbursement rate of digitally managed radiological images.

While the clinical acceptance of IMAC technology has be spotty in the past, a growing number of projects using newer technologies have increased clinical acceptance. As more competing products are introduced in all areas of IMAC technology, integration of radiology imaging systems will take place in various forms to improve overall efficiency of radiology service. IMAC technology is a special case of network computing which has become common in other areas. It will take some time to modify all radiological imaging systems to be network compatible. In some cases manufacturers of imaging systems are reluctant to provide connectivity for IMAC network.

A hospital cannot perform its mission of delivering timely and efficient health care without the collection and distribution of a mass of diagnostic, treatment, and management information. As the number of diagnostic and therapeutic procedures have increased, the information management requirements placed on hospitals by government and insurance industry have grown. Furthermore, as patient awareness of health issues has blossomed, hospital departments have turned from largely manual methods to computer based systems of many types. In general, though, the attitude about such systems has been somewhat self-centered in that each department or division tends to develop a system to solve its own problem as a primary goal with the concern of other areas considered secondary.

A fully integrated hospital information system will be able to

(a) Optimize the resource utilization,
(b) Lower communication costs,
(c) Improve quality of care,
(d) Minimize operational dependence on paper and film, and
(e)Facilitate effective research and education support.

Furthermore, various health care providers and patients will be able to gain a better understanding of the operations of the hospital as a whole. A fully integrated system as depicted here is not yet a reality, but that must be the goal for all communication and management information systems required to run a hospital. Challenges are numerous but we are closer than ever to reaching our goal of film independent imaging service throughout the hospital. Similar challenges have been met in other industries [33, 34] when a prudent management deployed computerized information management system matching the technical capability to the carefully targeted problem areas.

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Rationale for a Large Facility PACS Implementation

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ABSTRACT

The Wright-Patterson USAF Medical Center (WPMC) is one of three DOD medical centers currently engaged in the installation of the "Medical Diagnostic Imaging Support" (MDIS) system. MDIS is a comprehensive hospital wide "Picture Archiving and Communications System" (PACS). In defining the requirements for the MDIS system it quickly became apparent that detailed operational information was necessary to adequately define the system requirements. This information included an understanding of the needs of our customers, workload data, current and expected future imaging capabilities, current problems encountered in meeting the needs of our customers, and the resources available to respond to these problems. Armed with this information the MDIS technical development team was able to define a detailed functional description for the MDIS system. This functional description was presented to industry in the form of a competitive solicitation with the subsequent submission of proposals by interested vendors. Following an extensive review of these proposals and the results of live benchmark evaluations, a contract was awarded to Loral Western Development Laboratory on September 27, 1991. This paper presents an operational overview of WPMC, a description of the deficiencies in our current image management system, and a discussion of the PACS to be installed this summer.

1. INTRODUCTION

The introduction of new technology into our medical center must support our overall purpose and vision and must meet or even exceed the needs and expectations of our internal and external customers. Our medical center's purpose (our mission) is healthcare. We accomplish this mission by providing high quality medical care and service to the 50,000 beneficiaries in the local community we serve and, in addition, through providing specialized referral health services in support of DOD Region VI, containing some 900,000 beneficiaries and 14 military treatment facilities spread over a 10 state region. We are the largest military healthcare facility in the region. Another facet of our mission involves post graduate medical training in conjunction with a community based medical school (Wright State University School of Medicine). Preparation for wartime and peacetime contingencies is another key element of our mission. Although our mission adequately chronicles our everyday activities, it is our vision which motivates and drives this organization towards its future. The vision of WPMC is to become the center of excellence for healthcare delivery in the Department of Defense by employing state-of-the-art medicine and service using the principles of "Total Quality Management". MDIS will play a vital role in the transition of the medical center from its mission toward its vision.

2. DESCRIPTION OF THE CLINICAL ENVIRONMENT

In order to define the functional and operational requirements of a PACS it is first necessary to define, to the greatest extent possible, the nature and requirements of the clinical environment in which the system is to be used. This involves identifying your customers and their needs, obtaining pertinent workload data, identifying the modalities to be interfaced into the system, and the specific

definition of your objectives for the system. Although the patient remains the ultimate customer of the imaging process, there are a variety of other internal and external customers. The radiologists themselves are important internal customers of the process, but the prime internal customer is the referring physician. The main determinant of the quality of the imaging process, therefore, is how well it addresses the needs and requirements of the referring physicians. Among the key quality characteristics which the referring physicians expect of a quality imaging process are timeliness, accuracy, diagnostic reliability, ease of application, integration with other clinical processes and technical modalities, and optimal correlation of patient information.

2.1. Clinical Environment

Wright-Patterson Medical Center has a rated inpatient bed capacity of 301 with the ability to expand to over 400 beds if conditions warrant. At this time 252 of these beds are in routine use with an average occupancy rate of 81%. During 1991 there were 9887 admissions with an average length of stay of 6.4 days. Also during 1991 a total of 563,886 outpatient visits were performed. Table 1 shows the distribution of admissions and outpatient visits by clinical specialty. Services such as emergency medicine, flight medicine and primary care do not directly admit patients to the hospital, but instead refer patients requiring hospitalization to other specialties.

Table 1: Admissions and Outpatient Visits by Clinical Specialty

Specialty	% Admissions	% Outpatient Visits
Emergency Medicine		6
Flight Medicine		2
Internal Medicine	25	18
Mental Health	4	5
OB/GYN	19	7
Orthopaedics	11	5
Pediatrics	9	12
Primary Care		20
Surgery	32	7
Others		18

Table 2: Number of Radiographic Examination Requests by Clinic

Requesting Clinic	% of Inpatient Requests	% of Outpatient Requests
Internal Med	59	14.1
Surgery	19.6	10.8
OB/GYN	2.3	17.2
Peds/NICU	9.8	4.4
Orthopedics	6.5	10.4
Psychiatry	2.6	0.2
Primary Care	0	19.8
Emergency Medicine	0	18.8
Flight Medicine	0	3.0
Other	0	1.7

As can be seen from Table 2, over 56% of the outpatient requests for radiology services are generated by three clinics (OB/GYN, primary care, and emergency medicine) while 59% of the inpatient requests are generated by just one clinic (internal medicine). Of all radiographic examinations performed 22.7% are inpatient and 77.3% are outpatient.

The medical center's staff totals 1791 of which 118 are staff physicians and 119 are resident physicians in medical center sponsored residency programs. In addition, the medical center staff is supplemented with a total of 136 partnership physicians, other residents, and non-physician providers. Residency programs are offered in internal medicine, pediatrics, general surgery, OB/GYN, emergency medicine, psychiatry, clinical psychology and dentistry. The distribution of staff, resident, and non-physician providers is shown in Table 3.

Table 3: Medical Staff Composition and Workload for Selected Clinical Areas

Speciality	# Staff	# Residents	# Non-Physician Providers
Internal Med	31	25	
Surgery	30	43	5
Radiology	8		
Pathology	4		
Anesthesiology	7		16
Emergency Med	12	32	
Psychiatry	8	34	8
OB/GYN	6	24	3
Pediatrics	18	33	3
Primary Care	17		4
Rad Oncology	1		
Nuclear Med.	1		
Total	143	191	39

2.2. Radiology Department

The Department of Radiology is made-up of three services, diagnostic radiology, nuclear medicine, and radiation oncology with diagnostic radiology being the largest in terms of personnel, patient load, and image volume. Although our principle focus is on diagnostic radiology the imaging needs of nuclear medicine, radiation therapy, cardiology, orthopaedics, and urology were also considered in the design of MDIS.

Radiology is staffed with 8 radiologists, 1 nurse, 34 staff technologists, 8 student technologists, and 12 support personnel. There is one full-time department superintendent and one department manager. Three medical physicists share the responsibilities of diagnostic imaging, radiation oncology, and radiation safety. Transcription services are provided by the medical center's central transcription service which utilizes a combination of networked and stand alone personal computers. All transcribed reports are printed to paper with the subsequent deletion of the digital copy.

The majority of the radiology department is situated on the first floor of the hospital in the central core area This strategic location places the department immediately adjacent to such key section as nuclear medicine, emergency room, surgery clinic, orthopedic clinic, urology clinic and a portion of the clinical laboratory. The radiology department occupies a total of 22,111 square feet ex-

cluding MRI which is housed in a modular building adjacent to the main hospital on the basement level. Approximately 13% (2800 square feet) of this space is occupied by the film file room.

As shown in Table 4, WPMC is equipped with a full range of diagnostic imaging modalities. The MDIS system will serve to integrate all of these devices into a single image acquisition, distribution, and storage system.

Table 4: Description of Available Imaging Modalities

Modality	Model
MRI	GE 1.5 T Signa Advantage
CT	GE 9800 QUICK
Ultrasound	Acuson 128 XP/E
Ultrasound	Acuson 128
Special Procedures	Philips Ploy Diagnost UV
DSA	Philips Ploy Diagnost UV with Philips Analylical Processor
Cardiac Cath	Siemens BICOR
Radiography	GE dedicated chest unit
Radiography	GE dedicated head unit
Radiography	2 each GE model 46-1785002 w tomo
Radiography	Picker Rapido
Fluoroscopy	2 each Picker Vector 100
Fluoroscopy	GE MIS 1250 IV
Urology	2 each Xonics A6770010
Portable C-Arm	3 each GE model 46-914550601
Nuclear Medicine	Picker Digital Dyna Camera (used with ADAC 33000 Image Processor)
Nuclear Medicine	Picker Dyna Camera 4 (used with ADAC 33000 above)
Nuclear Medicine	ADAC Genesys (with ADAC 33000 Plus)
Nuclear Medicine	Siemens Body Scan (Dual Head) (used with Medesys Pinnacle)
Nuclear Medicine	Siemens LEM (with ADAC 3300 Image Processor)
Nuclear Medicine	Siemens Orbitor (used with Medesys Pinnacle)

The Department of Radiology performs 84,297 examinations per year which yield a total of 857,916 images per year. At the present time all of these images are viewed and archived on film. Table 5 presents a summary of the diagnostic radiology workload for 1991.

All diagnostic radiology images are stored within the Department of Radiology for a period of five years. This archive currently houses approximately 100,000 patient folders, containing an estimated 1,380,000 individual films with a total of 4,280,000 images. Approximately 17,000 of these folders are kept in active files located on the main department level with the remainder being stored in the file room basement. The basement storage area is accessible from the main file room by means of a stairway located within the main file room.

Table 5: Imaging Workload for Diagnostic Radiology

Modality	# Studies/ Year	Films/ Month	Avg # Images/Film	Images/ Month
Routines	48,334	10,232	1.5	15,348
Mammography	7,435	2,470	1.0	2,470
CT	5,129	1,521	12.0	18,252
US	9,353	2,060	6.0	12,360
MRI	3,376	1,327	12.0	15,924
Fluoroscopy	5,464	4,697	1.25	5,871
Portables	3,600	300	1.0	300
Angiography	1,606	774	1.25	968
Total	**84,297**	**23,381**		**71,493**

On average 325 transactions (film retrieval or film filing) take place at the file room window per day. This number includes requests actually made at the file room window and activities resulting from "pull lists" submitted by clinics for scheduled outpatient visits. File room activities are accomplished by five full-time clerks with augmentation by radiology technologists as necessary.

The radiology department is confronted with several operational issues that represent limitations and inefficiencies in the current system. Although some of these issues may complicate the implementation of MDIS, they are also viewed as areas where the MDIS technology can be exploited to improve operational efficiency.

(1) Films are read in individual radiologists' offices. The only assigned reading areas to which radiologists go for interpretations are inpatient and ICU boards, fluoroscopy, angio, and to a limited extent MRI.

(2) Few films are pre-hung for reading, those that are include ICU boards, fluoroscopy, and angio. All other films are pulled from folders by radiologists in their offices during interpretation. Historical films for these studies are not pre-pulled from folders except by mammography and ultrasound technologists.

(3) Due to personnel shortages there is a significant transcription backlog. For routine reports, the turnaround time from dictation to verification of hardcopy averages 4-7 days. Hardcopy report distribution time to requestor averages 1-3 days. All inpatient and urgent reports are transcribed on a same day basis. The situation has been alleviated somewhat by the use of a "Rapid Telephone Access System" (RTAS) digital voice archive system. This allows providers to access the dictated report in the radiologist's voice immediately after input.

(4) The Radiology Department does not utilize a radiology information system (RIS) nor does the medical center have a comprehensive hospital information system (HIS). A manual index card system is maintained to keep a current log of all files in the department. This system was designed to track filed films efficiently, but it is not utilized consistently and concordance of information on the cards and the main film folders is poor.

(5) There is no automated film tracking mechanism. Files are located by searching the expected locations based upon sign out information, type of examination, and radiologist work schedules in the case of interdepartmental searches. Manual searches and telephone

calls to locate films account for a great portion of the man-hours spent by file room personnel.

(6) An analysis of repeated exams shows that approximately 5% of the films taken must be repeated, 28% of these repeats are due to technique errors (i.e., films which are too dark or light). This means that on average 330 films must be re-accomplished per month due to technique errors.

3. OBJECTIVES OF THE MDIS SYSTEM

After identifying our customer base and defining their needs we were able to develop and refine a list objectives which then served as a guide in the preparation of the MDIS system specifications. These objectives, which might also be viewed as the expected MDIS benefits, fall into three general categories, improve image quality, productivity enhancement and improved image management. The specific objectives considered were:

(1) provide rapid access to completed examinations,

(2) allow images to be viewed at workstations located in clinical areas throughout the hospital,

(3) provide rapid access to completed examinations by locating image viewing workstations throughout the clinical areas of the hospital,

(4) allow the simultaneous viewing of the same image by multiple providers,

(5) provide a means to adjust the window and level settings and apply image enhancement algorithms to conventional radiographs,

(6) prevent the loss of images and reports,

(7) reduce radiation dose to patients,

(8) reduce the number of retakes due to technique errors,

(9) reduce film and chemical usage and storage requirements,

(10) provide lists of completed examinations pre-sorted by radiologist, radiology service, referring clinician, referring department, and inpatient unit,

(11) automatically fetch pertinent historical examinations based upon the type of examination scheduled, and

(12) provide the means to electronically move images between geographically separated facilities (teleradiology).

Information of this type was used by the MDIS technical development team to prepare a detailed functional description for the MDIS system. This functional description was presented to industry in the form of a competitive solicitation with the subsequent submission of proposals by interested vendors. Following an extensive review of these proposals and the results of live benchmark evaluations, a contract was awarded to Loral Western Development Laboratory on September 27, 1991.

4. THE MDIS SYSTEM

The engineers and scientists at Loral Western Development Labs, along with those of their principle subcontractor, Siemens Gammasonics, are currently in the process of finalizing the installation plan for the Wright-Patterson MDIS system. Installation of this system will begin in the spring of 1992 and will take approximately one year to complete. The following paragraphs provide a succinct description of the Wright-Patterson system.

4.1. System Architecture

MDIS is based on a modular, open and expandable design. This system utilizes an advanced, high speed, fault tolerant image server combined with 100 Mbps fiber data links to move images from acquisition devices to imaging workstations. MDIS imaging workstations are based upon the Apple Macintosh line of personal computers which have been enhanced with specialized processing and display hardware. A central host processor provides system control, database management, basic RIS, and security features. This system is linked to geographically remote sties through a gateway on the LAN and commercial or private telephone circuits. This architecture may be divided into four logical subsystems; communications and network, image database and storage, image acquisition, and image output and display subsystems.

4.2. Image Acquisition Subsystem

The MDIS system will acquire images from all of the imaging devices shown in Table 4. This will be accomplished by direct digital input, by utilizing computed radiology technologies, by digitizing film, and by digitizing analog video signals for devices which do not support a digital interface.

Image data from the General Electric CT and MRI devices will be acquired by a direct digital interface. These interfaces consist of an ACR-NEMA compliant modality gateway which is a PC based network interface unit that acquires image data via an ACR-NEMA physical interface and forwards this data via a PACSnet ethernet LAN. This data is communicated to a modality interface unit (MIU) which accepts simultaneous image transfers from several imaging sources and copies the image data to the shared file server.

Computed radiology (CR) provides the ability to perform most general radiographic procedures without the use of film. CR offers several advantages over the current film based system. The phosphor plate used in these systems is reusable, replaces film as the image receptor, eliminates the need for processing chemicals, and yields a digital image which can be processed and enhanced. Within the main radiology department we will install one Fuji 7000 high performance unit and one Fuji AC1+ medium performance unit. An additional AC1+ will be installed in the orthopedics department. Support for the operating rooms and a remotely located occupational medicine clinic will be accomplished using a Kodak Digital Phosphor Scanner.

Film digitizers will be used to acquire historical images currently stored in our film archives and film images brought in from other facilities. To capture these images two Lumisys Lumiscan 200 film digitizers will be placed in the radiology file room. These autofeed scanners can accommodate film sizes up to 14" x 17", have a throughput of 60 sheets per hour, and provide an image resolution of 2048 x 2560 pixels with 12 bits of gray scale.

Imaging devices which produce only analog video output, such as ultrasound, will be accommodated through the use of a video acquisition workstation. This workstation consists of a Macintosh IIFX workstation with a high performance video frame grabber and image memory. The

frame grabber digitizes ultrasound video to a resolution of 512 x 512 x 8 bit pixels and fluoroscopy video to a resolution of 1024 x 1024 x 8 bit pixels and stores the frames in an on board frame buffer.

4.3. Image Output and Display Subsystem

The image output and display subsystem provides hardcopy and softcopy image viewing and manipulation capability for the MDIS system. Softcopy viewing will be performed on a "softcopy image display-standarized" (SCID-S) or "softcopy image display-optimized" (SCID-O). In its present configuration Wright-Patterson will have 14 SCID-S workstations and 47 SCID-O workstations.

SCID-S's are designed to provide radiologists and other clinicians with primary diagnosis and reporting capabilities via two to eight high resolution, high brightness grayscale displays. SCID-S displays are portrait mode and are provided with one of two resolutions. "A" class displays have a resolution of 1536 pixels x 2048 lines, while "B" class displays have a resolution of 1024 pixels x 1280 lines. Both class "A" and "B" displays operate at non-interlaced frame rates of 70 Hz for flicker free presentation. Ten of our SCID-S workstations will be configured with four class "A" displays, while the remaining four will be configured with two class "A" displays.

SCID-O's provide a lower cost softcopy viewing capability for routine clinical viewing of images throughout the hospital. These workstations provide up to four, high brightness, flicker free, grayscale, landscape displays with a resolution of 1152 pixels by 882 lines. Other than the display resolution and associated memory, the SCID-O is identical to the SCID-S. All 47 of the SCID-O to be installed at Wright-Patterson will be configured with two displays.

Hardcopy output is provided by a Kodak Ektascan laser printer located in the quality control area of the main radiology department. This laser printer is interfaced into the MDIS network via a Macintosh IIFX based camera server which retrieves images from the shared file server in background. A SCID-O workstation equipped with an Agfa Matrix imager will be used to produce high resolution 35 mm film images.

4.4. Communications and Network Subsystem

Images and data are moved via a fiber optic distribution system configured in a "star" with the WSU at its center and acquisition interfaces and workstations at its periphery. This arrangement allows for images to be displayed in two seconds or less. User requests, system control traffic, and images acquired via modality and teleradiology gateways are transported over multiple ethernet tributaries with bridge units to an FDDI backbone.

4.5. Image Database and Storage Subsystem

The patient database organizes all information on patient examinations in a multiply redundant, high performance relational data base using the clinically meaningful metaphor of a master folder containing a hierarchy of subfolders. The patient database contains information about patients, examinations, and references to image storage locations. The image data itself is stored in the Working Storage Unit. This database in constructed in SYBASE and runs on a VAX 4000 computer.

Within the MDIS system images are stored on a combination of "write once/read mostly" (WORM) optical disk and high speed magnetic disk. The MDIS system utilizes a Kodak Optical Disk Jukebox (ODJ) for archival storage while the Loral Working Storage Unit (WSU) serves as a high speed shared file server.

The Kodak ODJ provides a robotic mechanism for the on-line storage of 100 optical disks measuring 14 inches in diameter. Each of these disks is capable of storing over 10 GBytes of data

which combine to yield a storage capacity of over 1 TByte per ODJ. This storage capacity can be increased by several times through the judicious use of data compression. In the Wright-Patterson configuration two 100 platter ODJ's will be used for archival storage.

Rapid access to recently acquired examinations and de-archived historical images is provided by the WSU. The WSU is configured as a redundant array of inexpensive disks (RAID). Forty disk drive modules are supplied with each WSU. Thirty-two drive modules contribute one bit each to an internal 32 bit word. Seven additional disk drive modules are used for single bit error correction. These 39 disk drive modules are written to and read from simultaneously. A 40th disk drive module serves as a hot spare. In this configuration the WSU achieves an aggregate data rate of approximately 320 Mbits/sec. To fully utilize this data transfer rate, each WSU can be configured with up to 28 input or output channels. Each channel can input/output data at rates up to 100 Mbits/sec. A fiber optic image distribution system allows each I/O channel to service up to 32 acquisition units and/or workstations. One 38.4 GByte WSU will be installed at Wright-Patterson. Since all data stored on the WSU is compressed approximately 2:1 the storage capacity of this device is effectively doubled.

5. CONCLUSIONS

With the installation of MDIS, the referring physician will have the nearly instantaneous access to all the current and prior digital images of the patient along with the simultaneous display of the interpretive findings. The digital nature of the images permits a wide range of manipulation of the data to insure obtaining the maximal amount and the most accurate patient information. Another important by product of this technology is how effectively it will contribute to the ability of the radiologist to participate in direct patient care. This will be accomplished through the strengthening of his collaboration with the referring physician as a concomitant of implementing the MDIS process. When MDIS installation is complete, the need for film storage will be markedly reduced eventuating in savings of both space and personnel as well as the elimination of the bane of all radiology departments, lost film. MDIS will facilitate the education mission of the medical center by allowing simultaneous review of images by instructors and students along with full exploitation of all information contained in multiple available images from different modalities.

Another property of MDIS that will be of great assistance in helping this medical center move towards its vision is the inherent capacity for teleradiology This capability will not only support the specialty consultation activities of the medical center with relation to DOD Region VI, but, moreover, will allow incredible technological support to the broadly based managed healthcare initiative recently inaugurated by the organization. Teleradiology holds great promise for strengthening the development of provider networks critical to the success of managed healthcare.

MDIS will revolutionize the imaging process at this medical center and will be supportive of its customer focused, process centered management approach. In addition, it will be an effective modality to accomplish WPMC's mission and help move the organization toward it vision of achieving excellence in healthcare delivery.

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Design strategy and implementation of the Medical Diagnostic Image Support system at two large military medical centers

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ABSTRACT

The Medical Diagnostic Imaging Support (MDIS) system contract for federal medical treatment facilities was awarded to Loral/Siemens in the Fall of 1991. This contract places "filmless" imaging in a variety of situations from small clinics to large medical centers. The MDIS system approach is a "turn-key", performance based specification driven by clinical requirements.

1. INTRODUCTION

Designing and implementing a large PACS system is a formidable task which has not been fully realized yet. This paper will share the highlights for design strategy and installation of the MDIS system at Madigan Army Medical Center (MAMC), Tacoma, Washington, and Brooke Army Medical Center (BAMC), San Antonio, Texas. The installation at MAMC represents features of installation for a new hospital opening March, 1992. This is a 1.2 million square foot, 416 bed facility with a large outpatient clinic capacity (more than one million outpatient visits/year). Approximately 400 physicians representing nearly all subspecialties (most with residency programs) work in this major tertiary care medical center for the U.S. Army. BAMC represents an installation for an existing facility highlighted later in section six. This paper will discuss personnel infrastructure, configuration planning, installation planning, and training issues for a full PACS implementation.

2. PERSONNEL INFRASTRUCTURE

An important aspect for successful installation of the MDIS system is the degree of involvement and supervision provided by key personnel. This is primarily the project manager, system administrator, chief x-ray technician, and industry supplied personnel.

2.1. Project manager

The project manager, generally a radiologist, provides overall guidance to the design and implementation strategy. An understanding of the clinical operations within radiology and throughout the hospital as well as digital imaging is essential when implementing a "filmless" environment. He acts as a facilitator working closely with the radiologists, clinicians, administrators, technologists, receptionists, and transcriptionists concerning configuration, installation, and training issues.

2.2. Systems administrator

A systems administrator with a background in computer science and preferentially experience with PACS operations is needed to oversee the day to day operations of the MDIS system. This person represents the government's interest for technical contractual issues and serves as an advisor to the project manager and at MAMC is involved with the installation of the hardware and software in a detailed manner.

2.3. Chief x-ray technician

The chief x-ray technician is an advisor to the project manager concerning planning and implementation. At MAMC this person also acts as the department of radiology's transition coordinator providing valuable insight and information regarding the interaction and impact the MDIS system will have in the new hospital. His perspective as an x-ray technician guided the clinically driven MDIS system specification in many ways. Further assistance will be fostered by strategic placement of this key individual as one of our supervisors for the diagnostic

radiology section, facilitating a smooth transition for the receptionists, transcriptionists, and x-ray technicians to the MDIS system.

2.4. Industry personnel

The MDIS system contract provides for "turnkey" operation and maintenance of the system for up to eight years. This is accomplished by industry supplied personnel; a system engineer, database/archive manager, and two computer technician/trainers at the larger medical centers. The system engineer manages the optimal operation of all the computer components of the MDIS system, including databases, image transmission, interfaces, and electronic image archives. The database/archive manager is responsible for all aspects of image management including archiving, both electronic and hard copy. The computer/technician trainer performs necessary maintenance and on site repairs. He/she is also proficient in the operation of all components of the system, and fully capable of training others in the proper operation of the equipment. The MDIS system contract defined the specific credentials of these individuals to ensure qualified personnel are provided.

3. CONFIGURATION PLANNING

Major areas for configuration planning involved the archive, image acquisition devices, workstations, RIS system, and fault tolerance. A unique aspect for the MDIS system was use of a clinical scenario to drive the overall configuration. Based on this scenario, the prospective offeror proposed a "turnkey" system in a competitive bidding process awarded to the vendor with the system having the best value to the government.

3.1. Archive

An archive definition used for the MDIS system was based on the concept of three levels of image storage: long term archive, short term storage, and local workstation image storage. A long term archive was defined as enough capacity to store two years worth of images on-line with an additional three years stored off-line. A significant feature for the design of the system is the use of image compression. The MDIS system accepted a 10:1 lossy compression algorithm for computed radiography images in a long term archive and approximately 4:1 or less for other digital images. Images not yet interpreted must use a lossless compression scheme. This resulted in a long term archive solution utilizing two optical disk jukeboxes for a total of two terabytes of on-line image storage allowing Madigan Army Medical Center to store approximately 500,000 exams on-line (2.5 to 3 years worth). Overall, MAMC produces more than 190,000 radiology exams/ year for a non-compressed storage need of approximately 3.7 terabytes each year.

Short term storage is designed to hold inpatient images for the average length of inpatient stay (4.5 days for MAMC), all outpatient images for 48 hours, all exams not yet interpreted, and pertinent historical images. Local workstation storage was defined to hold one day's worth of work for the diagnostic workstations and two days worth of images for review at the clinical workstation. The MDIS system solution eliminated the need for local workstation image storage. A proprietary Working Storage Unit (WSU) provides enough capacity and speed to combine the functions of short term and local workstation storage by using 40 disks (magnetic media) operating in parallel. Images are compressed approximately 2:1 and stored as 39 bit words, 32 bits for image data with 7 error correction bits. Each bit is stored on 39 separate disks with one disk operating as a hot spare with single bit errors (e.g., a single disk failure) being detected and corrected without any loss of operations. A total capacity of 64 gigabytes of image data is available on the WSU. Image retrieval bandwith is greater than 400 CR image equivalents per minute from multiple workstation sites. Simulation data demonstrated the peak WSU utilization at MAMC would be 85 CR image equivalent requests per minute, providing sufficient reserve for growth.

3.2. Image acquisition devices

The MDIS system is designed to interface computed radiography, computed tomography, magnetic resonance, ultrasound, fluoroscopy, angiography, and nuclear medicine images. Details of these interfaces are beyond the scope of this paper. Rather, the key issue for configuration planning is the number of computed radiography readers required based on different operational areas, level of CR reader performance, different plate size requirements, and peak image processing throughput rate.

There are five basic areas at MAMC where CR images are processed on a mature MDIS system: main radiology, orthopedic clinic, medical intensive care unit, urology clinic, and the troop medical clinic. The peak

image processing throughput rate in main radiology calculated for the clinical scenario is 200 CR images at the busiest hour of the day which is satisfied by two Fuji 7000 and AC-1 plus CR readers. These are placed in two major work cores and can support all image plate sizes currently offered. The orthopedic, urology, and troop medical clinics only need an AC-1 plus CR reader supporting a maximum peak image processing throughput rate of 40 images per hour. The medical intensive care unit will utilize the base performance CR reader with a peak image processing throughput of 20 images per hour and two image plate sizes, 14 x 17 and 8x10 inches. All together, eight CR readers will be installed at MAMC of various performance levels.

3.3. Workstations

There are two basic workstation types in the MDIS system, diagnostic and clinical. The diagnostic workstations can have two to eight monitors, while the clinical workstations have one to four monitors. Workstation functionality will not be discussed except to say that the full CR image data set is available to all workstations and that the software user interface is the same for all. The number of diagnostic workstations required for "filmless" operations at MDIS system sites are based upon the number of radiology staff and residents, subspecialty mix, exams read per workstation per day, non-radiology user requirements, and teleradiology operations.

The department of radiology with 14 staff and 16 residents at MAMC divides the workload primarily along subspecialty lines; chest, gastro-intestinal, musculoskeletal, genito-urinary, pediatric, mammography, ultrasound, magnetic resonance, emergency medicine, interventional/ angiography, and nuclear medicine. The mammogram exams will not be acquired or read on the MDIS system at this time. The computed tomography exams are read by their respective subspecialty areas (e.g., chest CTs are read by the chest radiologists), especially suited for the PACS environment.

The number of exams expected to be read at each workstation per day is approximately 50-75. Nearly 800 exams are read each day based on 250 working days per year. Approximately 11 to 16 workstations will be required based on these numbers. The chest, musculoskeletal, and magnetic resonance sections need two workstations each based on workload. Three areas outside of radiology will have diagnostic workstations; pulmonary medicine, urology, and orthopedic medicine because of the more intensive use of images in these clinical specialties. The total number of diagnostic workstations at MAMC is sixteen, in most cases configured with four 2K monitors. Additionally, the department of radiology has nine clinical workstations to supplement reading capability as well as provide reviewing stations for clinicians. Portable teleradiology workstations are utilized for radiology staff, second tier resident, and nuclear medicine physician on call.

Clinical workstations are distributed based upon the number of clinics and wards, geographical size of a given clinic, number of clinicians per clinic at peak utilization, the percent of time each type of clinician reviews images, and the number of conference areas where patient images are reviewed. One example is the family practice clinic which has as many as 20 physicians seeing patients simultaneously and reviewing images approximately 20% of their time. Minimally, this would result in one workstation for every five clinicians for a total of four. One additional workstation is added for use in their conference room. Generally, workstations are placed in common viewing areas and utilize two "1k" monitors. Overall, 80 to 90 clinical workstations will be placed outside of the department of radiology at MAMC.

Two areas without workstations are the fourteen operating rooms and two shock/trauma rooms in the emergency department. These are low volume viewing areas and placement of workstations in these areas was not considered cost effective. Our solution is to print hardcopy images required for surgery on an ad hoc basis. The surgeons can select those images and quickly print them from any workstation onto a network laser imager. Each CR exam obtained on patients in a shock/trauma room, on the other hand, will routinely have the hardcopy images printed as well as sending the image data to the MDIS database. This will support a significant number of these patients going to surgery or being transferred to another medical facility where their images would be required for continued medical care.

3.4. RIS system

The MDIS system was designed to be interfaced with the DoD's Composite Health Care system (CHCS) hospital information system. In the event that CHCS is unavailable, an Interim-RIS (I-RIS) is provided with basic functionality and possessing common data elements as CHCS for future compatibility. The I-RIS terminals share

multiple purposes including patient registration, report transcription, and report approval. The number of I-RIS terminals is dependent upon the number of patient registration locations, peak throughput rate of patients registered, number and location of transcriptionists, and the number of reports requiring approval. Twenty-five terminals will be in place at full system maturity with seven registration terminals in five locations, eight transcription terminals in four locations, and the remainder scattered about for report approval. Additional report approval capability is provided at diagnostic and clinical workstations.

3.5. Fault tolerance

The MDIS system specification requires a 99% system and 95% component uptime. This functional requirement drove fault tolerant configuration decisions by the MDIS system contractor. The more significant fault tolerant features involve the central file server (WSU), network, and CR readers. The WSU uses a redundant array of inexpensive disks (RAID, type 2 architecture). It was originally designed for management of reconnaissance imagery for the U.S. Airforce. The WSU is connected to a fiber optic network via a modified star topology which has an inherent risk for a single point of failure. A single disk failure can be detected and recovered with this architecture. Additionally, images are archived to the optical disk jukebox as soon as possible after acquisition to limit the data lost should two disks fail simultaneously. The simulation data as well as operational experience has demonstrated this file server has enough reliability to support the MDIS system requirements.

The fiberoptic network distribution hubs are also vulnerable to failure. Some fault tolerance is achieved by having workstations in the larger clinics divided between different distribution hubs so only half of the workstations would be disrupted with this type of failure. Additionally, excess fiber trunks are pulled to distribution points to allow for an expected attrition rate of individual fibers.

The CR units individually must meet a standard of 95% component uptime. However, their role in a catastrophic network failure is to allow printing of hard copy images from the integrated laser imager and processor at each Fuji 7000 and AC-1 plus CR reader. Additional hardcopy fault tolerance is achieved by CT, MR, US, fluoroscopy, and angiography images being produced directly by network independent laser imagers. Traditional film/ screen radiographs can also be produced at any time necessary by maintaining several daylight loaders and docked film processors within the department of radiology.

4. INSTALLATION PLANNING

The installation planning involves the MDIS system computer room, HVAC, electrical and plumbing, ergonomics, implementation phasing, and industry requirements.

4.1. Computer room

The optimal location of the MDIS system computer room is within the department of radiology to allow for greater operational control. For MAMC, this was achieved by reallocating some planned file room space to become the MDIS system computer room. Recovering some existing file room space might also be a good approach for existing facilities. However, a previously built computer room no longer utilized for that purpose will be renovated for the MDIS system at Brooke Army Medical Center. The correct size for the computer room must take into account the physical size of the equipment, maintenance access requirements, and allow for future growth of the system. This resulted in a computer room approximately 1200 square feet in area at MAMC. An uninterruptible power supply is another important consideration for a graceful shutdown should power or HVAC fail.

4.2. HVAC

Additional HVAC capacity is important where a grouping of equipment or individual hardware has a high rate of BTU production. The former situation was found in two large reading room locations at MAMC with six workstations in each and the latter regarding the CR unit placements. The CR readers produce approximately 5000 BTU's per hour which was anticipated. However, the expected hardcopy printing solution was a centralized one using a networked laser imager. The final MDIS system solution provided an integrated laser imager and processor with each CR unit adding an additional 18,000 BTU's per hour of heat production. This required adding additional HVAC capacity in these locations at MAMC.

4.3. Electrical power and plumbing

Electrical and plumbing requirements resulted in some physical plant changes. Wherever possible, equipment was placed near pre-existing drains, usually the CR units next to plain film daylight loaders and processors. The placement of the networked laser imager in the file room was the only location at MAMC where a new drain placement was needed.

The power requirements involved the determination of hardware voltage needs, number of outlets, and amperage of new and existing circuits. Most of the equipment uses 125 volts including the workstations necessitating only the addition of a few outlets where none existed or competition from other equipment was a problem. The amperage of existing circuits (typically 20 amps) did not turn out to be a problem since enough independent circuits were present. The areas of concern were the two large reading rooms where each diagnostic workstation uses slightly more than 5 amps. A few larger pieces of hardware such as the CR units, WSU, and optical disk jukeboxes use 208 V requiring additional power from the original hospital design. Enough excess hospital capacity existed to merely pull a new circuit to the needed locations.

4.4. Ergonomics

The more important workstation ergonomic factors are related to lighting, work surfaces, and chairs. The monitor brightness has been a problem with softcopy viewing, especially with 2K monitors. A traditional view box typically has a luminance of 200 foot-lamberts with a radiograph mounted. This is compared to 25-30 foot-lamberts for earlier 2K monitors, and 60-80 foot-lamberts for newer models. The lighting conditions in our reading areas have been supplemented with recessed, variably controlled incandescent lighting to limit the amount of ambient lighting to optimize viewing conditions. Another problem to solve is reflection and glare of the monitors glass surface from other workstations and several wall mounted view boxes. Our solution is placement of partitions between workstations in common viewing areas. The work surfaces provided were large enough to support the monitors, keyboard, mouse, telephone, dictaphone, and working papers. Finally, the chairs supplied by the MDIS contract are ergonomically designed for the user who must spend long periods of time at the workstation such as the radiologist.

4.5. Implementation phasing

Three major factors influenced the implementation phasing at MAMC; historical comparison images, user familiarization, and the timeline for other MDIS system installations. The original concept was to have three phases over 24 months. This was changed to a 12 month, two phase approach, with a mature system installed by March 1993. The trade-off to this overall accelerated installation rate was a slightly less robust initial capability, namely fewer workstations and a later interface implementation to ultrasound and nuclear medicine images.

A major consideration for transition to a "filmless" environment is how to assimilate the large number of historical comparison images into the data base. The digitization of more than 3 million films in the MAMC file room would be impractical. The MDIS system solution is to run a "parallel" system for the first year, building up the digital historical image database for all new exams, while printing a hardcopy to be read, filed, and retrieved as in the usual film based system. Additional older comparison images will be selected for digitization by the radiologists and clinicians as patients present to MAMC for treatment. This will provide the vast majority of comparison exams needed from the MDIS system database when all the workstations are installed throughout the hospital.

Changing from a film based to softcopy diagnosis and review environment requires a period of user familiarization. This will be accomplished by a combination of initial training by the vendor followed by the use of the initial workstations by the radiologists and clinicians on a periodic basis until full implementation. The radiology staff and residents will rotate to the Emergency Radiology workstation at MAMC one or two times per month for a full day of familiarization each time. The clinical staff will have a workstation dedicated for image review in the radiology department as well as one in the ER and MICU. The project manager will work with all the radiology physicians and most clinicians individually, especially the first several months. A major strength of the MDIS system diagnostic and clinical workstation is the Macintosh computer user interface (Mac II fx platform) with adaptations and additions for the medical imaging environment. This allows each new user to quickly become facile and proficient enabling them to train others as well.

4.6. Industry requirements

A successful "turnkey" installation of the MDIS system necessitates a close interaction with the vendor. Each MDIS system site provides information concerning equipment, facility specific installation requirements, computer room characteristics, facility drawings, and workload statistics. This is followed by a site visit with emphasis on placement of the equipment for subsequent installation.

At MAMC, the manufacturer and model of each piece of equipment to be interfaced to the MDIS system was provided. This also included any available ACR-NEMA interfaces. Facility specific installation information such as construction codes, cabling practices, plumbing details, HVAC capacity, and electrical power availability was detailed. Computer room characteristics provided were the location, size, and intrinsic HVAC capacity. Scaled architectural drawings were given to the vendor with a first approximation for MDIS system equipment placement. Additional power, HVAC, fire, plumbing, and communication drawings of the areas necessary for installation were identified and provided during the site visit.

5. EDUCATION AND TRAINING

Fundamental operational changes occur when making a transition to a "filmless" environment. The educational and training process must actually begin far in advance of the equipment installation continuing through complete system maturation. The project manager at MAMC began raising the institutional awareness of the MDIS system in the summer of 1990. This occurred mostly through one-on-one interactions with radiologists, clinicians, administrators, receptionists, and transcriptionists with additional group lectures on a periodic basis. The most important aspect during this process is to create a realistic level of expectation of how the MDIS system works. The operational differences were emphasized such as the change to common workstation viewing areas versus the previous practice of viewing radiographs in individual offices. This change in practice and potential inconvenience was generally considered acceptable in concept when the clinicians realized the images and transcribed reports would be available whenever requested.

The emphasis changed to operational training as the first phase of implementation approached. The vendor will supply initial and some follow-up training for radiologists, clinicians, radiology technicians, administrators, receptionists, and transcriptionists on the appropriate portions of the MDIS system. Additional one-on-one training is provided to the radiologists and clinicians by the project manager as described in section 4.5.

6. LARGE FACILITY RETROFIT INSTALLATION

Brooke Army Medical Center (BAMC) is one of the largest medical treatment facilities in the U. S. Army Medical Department with over 600 inpatient beds and outpatient services which cover the full range of major specialty and subspecialty care provided in tertiary care facilities. Additionally, the facility is a Level I trauma center (one of three in the metroplex of over 1 million people).

6.1. The facility

The hospital occupies multiple buildings which are spread out over a large area. The MDIS system is to be installed in three principle buildings: the Main Hospital, Beach Pavilion, and a Troop Medical Clinic. The Main Hospital was constructed in 1937, and represents approximately one third of the inpatient beds at BAMC. Important services include the Emergency Department, the general practice outpatient clinic, OB-GYN and newborn nursery, neonatal ICU, General Surgery and the SICU. Other outpatient and inpatient services are present. Radiology has a diagnostic service in the Main Hospital and performs general service for both inpatients and outpatients. The vast majority of fluoroscopy and ultrasound examinations are performed here. A new CT scanner has recently been added at Main. Radiation Therapy is also located in this building.

Beach Pavilion is located approximately one mile south of the Main Hospital. This building was constructed in 1931 and became part of the Hospital during World War II. Approximately two thirds of the inpatient beds, other ICU's (MICU, CCU, SICU, pediatric ICU and neurosurgical ICU), the majority of in- and outpatient services of Internal Medicine and the Surgical subspecialties, and Pediatrics are located in this building. Radiology maintains a second general diagnostic service, Special Procedures Section, ultrasound, CT, MR and Nuclear Medicine Service in this facility. Approximately, one mile from each of the above two facilities is the Troop Medical Clinic which contains two general radiographic exposure rooms.

Four large film file rooms are present in these three buildings containing the general plain films performed within the past 4 years. An additional one year of films is maintained at another film storage site within a warehouse located approximately two miles from Beach Pavilion and three miles from the Main Hospital. Two inpatient file areas and 6 specialty (CT, MR, US, etc.) file rooms are also maintained at different locations within the two main buildings.

6.2. Personnel

The Department of Radiology currently consists of 14 staff radiologists and 24 diagnostic radiology residents. A similar approach to that at MAMC was followed involving other key personnel in the MDIS project with selection of a project management officer, systems administrator and chief radiologic technician. The same four key industry provided personnel will be present at BAMC.

6.3. Workload

The current workload is similar to MAMC. Approximately 180,000 examinations were performed in 1991. This volume was distributed between approximately 60% outpatient and 40% inpatient work. The average length of inpatient stay for image storage calculations for BAMC is 6.8 days. About 50% of the workload was performed at Beach Pavilion with the combination of Main Hospital and the Troop Medical Clinic performing the other half. The majority of the digital imaging (CT, MR, Nuclear Medicine, DSA) was performed at Beach Pavilion.

When this annual workload is compressed to 250 regular working days for calculation purposes, BAMC generates approximately 1600 plain film images and 3600 digital images (either direct digital or frame grabbed) per day. There is an average of 3.5 films obtained per examination comprising of approximately 50% 14" x 17", 30% 10" x 12", and 20% 8" x 10"plain radiographic images. Altogether, this represents nearly 15 gigabytes of digital information produced each day.

6.4. Installation planning

A phased approach to installation is planned for BAMC. Key preparatory work includes intrafacility marketing, training, and general concept education. Introducing this technology involves changing the accepted way radiology and clinical medicine is practiced today as well as the way they interact with each other. Certainly, the experienced gained from preceding phased installation at MAMC and other MDIS sites will be utilized in the implementation at BAMC. The U.S. military medical department has the advantage of any other large health care organization of being able to share lessons learned between facilities when making new system introductions.

An additional need for phasing was based upon the funding flow. A large system of this magnitude has a noticeable impact upon the medical equipment budget of a service and the approach of phased funding over different budget years was taken. This drove the installation timeline as funding was provided for one installation phase at a time.

The initial plan was to install the system over three phases with one phase per year. Operations were to commence in the Main Hospital with database and image storage installation, and computed radiography units being installed in the Diagnostic Service and the Emergency Department radiographic room. Connectivity to the other input devices at Main Hospital (CT, US, fluoroscopy) was to be accomplished at this time. Workstation installation was to be initiated in the Radiology Department and in several of the clinical service wards and clinics. The second and third phases of installation were to include similar initial acquisition device placement and connectivity at Beach Pavilion and subsequent proliferation of multiple workstations within the Department and in various wards and outpatient clinics.

Radiology information terminals (I-RIS) would be gradually installed throughout the department as the image acquisition and display capability was expanded. Once CHCS is installed at BAMC, the initial number of MDIS I-RIS terminals (27) will be greatly expanded to provide easier access to the database throughout the Department at these text-only terminals, principally for report entry and review/approval.

The installation at BAMC is designed to produce as filmless a Department of Radiology as possible. Budgetary constraints resulted in a limited ability to produce the same level of "filmless" implementation as MAMC. This is revealed in the disparity of the number of clinical workstations designed into the BAMC scenario when compared with the MAMC scenario. Thirty-three workstations have been planned outside of the Department. The approach and concept utilized is digital films being printed for designated clinics where insufficient workstations are initially provided to support the required viewing demand in these locations. Additional workstations will be added in these areas as funding is available. This funding may be acquired by the individual hospital service and added in a piecemeal fashion or could be done on a more complete effort as an additional phase of installation, likely resulting in a more economical installation.

The initial phasing approach was modified similar to that of MAMC with initially less image display capability in Phase I, but with earlier completion of the entire project than initially planned. The installation plan was reduced by over one year, to completion at approximately two years from time of contract award. This will result in compression of the learning and familiarization process previously planned. This will have particular impact at a distributed building facility such as BAMC with a nearly complete transition at one time from a completely film based system at Beach Pavilion to a potentially relatively filmless system in a short period of time, allowing less familiarization time for radiologists, technologists and clinicians.

6.5. Problems encountered with retrofitting a large center

The list of difficulties encountered in performing a retrofit on an aged, distributed medical center is only now being compiled. This installation presents many problems which may be found to a lesser degree in newer facilities and are not expected to be encountered at MAMC. A few examples of such problems encountered to date are discussed here but by no means, does this represent an exhaustive list.

An important feature that a vendor is seeking from the user in planning the installation of a system is the availability of as-built drawings of the current version of the facility. As we have found, buildings built decades ago which have potentially undergone hundreds of major and minor modifications upon one system or the other simply may not be accurately represented on the current version of a set of "as-built" drawings. This may have a critical impact upon the current vendor in his ability to perform planning for a facility and require much more extensive on-site investigation by the installer in concert with the building engineers.

The particular type of electricity required by any given piece of hardware may not be available within the old building. Additionally, current power supply panels may not have sufficient capacity or have available additional circuits required by the new equipment. This may require long runs of new cable to remote sources of power, even outside of the building, to provide adequate power of the necessary voltage and phasing to operate the various pieces of equipment.

Air conditioning and ventilation may be totally inadequate to support the heat production of various components of a large integrated system. Because certain components tend to be concentrated in local areas like a computer room or a radiology reading room, careful calculations of the adequacy of the A/C requirements is necessary. Not only does this have to include all of the new equipment being added to an area, but must also include the existing equipment in the same environmental zone which will remain and continue to contribute to the regional heat production. Adequate ventilation must be provided for such components as a laser film printer and film processor.

Hidden environmental problems such as the presence of asbestos must be planned for in a system installation. This may be encountered in regions that the installer was planning to utilize for cable runs, for example. This may come as a surprise to all concerned, including the current building engineers who might not have access to prior knowledge of its location, this institutional knowledge having been lost over the years. Thus, alternative planning should be performed from the beginning in the event that these conditions are encountered.

Other problems relate to building design, computer room, and local construction restrictions. Older facilities usually do not have modern design characteristics such as interstitial spaces or raised computer floors in required locations and planning must include how to install or accommodate these deficiencies. Additionally, another potential problem which should be investigated from the outset is the impact of local building codes or historical societies. Vocal historical societies may necessitate changing from simple solutions utilizing the outside walls of a structure to more difficult solutions requiring concrete floor drilling inside of the structure.

6.6. Conclusions to date for this retrofit

A phased installation plan is required for a project of this magnitude being installed into an existing, operating facility. This conclusion is based upon many principles including the expectations of the rapidity of change that will be required in the daily work habits of the user's of the system, the education requirement efforts which will be required for the users, the ability to obtain funding for phases versus funding a complete system all at once, and the expectation that lessons will be learned as the installation progresses in phases which can be successfully applied to later phases of the project.

The current MDIS system design will accomplish the goals of producing a high level of filmless operations within the radiology department, bring the image loss rate to a minimum, and make these images available to all radiologists and residents within the department regardless of their point of acquisition or display.

Additional workstations will be required in the clinical areas of the hospital to achieve the long term goal of a highly filmless hospital. After achieving this more complete access capability to the image file, enhanced productivity will be seen among all of the professional and paramedical personnel of the hospital campus as they spend less of their time searching the multiple reading rooms and film file rooms for images on their patients.

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PACS in an Old Hospital
The Brooke Experience

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The installation of a PACS system into an old, multi-building facility at Brooke Army Medical Center brought with it a series of problems and opportunities. The two primary buildings at BAMC were built in the 1930's and certainly were not built to accommodate either computer systems or to assist the planners or installers with their implementation of this PACS system.

Principle opportunities of the PACS installation center around overcoming the primary inefficiencies of the current film-based radiology system at BAMC. These inefficiencies revolve around the accountability, transportation and storage of film in a distributed Radiology Department which occupies space on multiple floors in multiple buildings on the BAMC campus.

Problem areas encountered during the installation centered around basic items such as the availability of adequate power, air conditioning and water/sewer access for the added pieces of equipment coming into the Radiology Department, primarily. The older structures had no interstitial spaces for utilities or the routing of fiber optic or other communications networks. No communications closets or cableways/trays are present in either building. Adequate current as-built drawings of the facilities were non-existent for such a massive undertaking which involved essentially the whole of both large buildings. Much core drilling through concrete floors had to be performed to accommodate the long expanses of fiber optic cable rising through both buildings. This work had to be accomplished in the midst of a functioning hospital fully involved with daily medical and surgical patient care. Noisy and dusty activities had to be planned around the patient care activities and the evening sleep hours. About the only advantage of a retrofit to older structures is that surface mount technology might be employed in final routing of fiber and network material as the physical appearance of such may not detract from the existing appearance of the structure (potentially useful if not counter to the desires of local historical societies).

Two important aspects of installation of the MDIS system at BAMC were of particular importance and require in depth discussion. These will comprise the bulk of

this presentation. First, BAMC had an existing Radiology Information System which the integrated RIS within the MDIS database supplanted. Secondly, a massive training program for both Radiology and Clinical personnel was undertaken during the initial installation of the MDIS system.

RIS Implementation

At BAMC, the MDIS system was installed into a hospital which had an existing Radiology Information System. This RIS (TRIRAD) contained approximately eleven years of patient database. Important information elements within TRIRAD included the patient name, ID number, telephone and address information, listing of exams, date of exams, the exam reports film folder storage location, and folder loan information. While the basic patient demographic and exam information was maintained on-line in the TRIRAD system, most of the exam report text was maintained off-line on magnetic tape.

The initial issuance of the MDIS implementation contract did not contain any capability for the conversion and incorporation of an existing patient database. This was because most of the proposed MDIS sites did not have these existing electronic databases. One crucial element of the BAMC TRIRAD database is the film folder location information stored in the TRIRAD system. In a facility with multiple file rooms and no real scheme as to which file room a given patient's master film folder might be stored in, access to this existing stored electronic information is vital for continued operations of the Department. This would be the case whether a complete PACS system was installed with near total filmless operations commencing or whether film based operational procedures would continue with a gradual phase in of filmless scenarios. This later situation is what is being followed at BAMC. Even in the extreme environment of totally switching to filmless operations immediately, patient's older exams would still need to be located for comparison to the newer studies being acquired, stored and interpreted electronically. Thus, the successful continued operations of the Radiology Department required the initial maintenance of the older database with plans established for eventual incorporation of this database into the MDIS integrated RIS.

A plan was also developed to allow the eventual electronic downloading of the patient demographic, reports and film folder locations from the existing RIS to the new RIS. This will then allow the termination of all activity on the original RIS. This transfer of patient database information should always be considered as an essential component of transition from one RIS to another. Not only will vital information such as film folder information be preserved, but the efforts required by reception personnel will be kept to a minimum if existing patients can be located in the new RIS without

having to go through the information gathering process which comprises the initial patient registration process.

Initial clinical operations of the MDIS system were begun at the end of March 1993 with a transition period planned to move from one RIS to the other. This transition period followed extensive classroom and hands-on training in the various functions of the MDIS RIS. The transition at BAMC also involved a period of dual entry of patient and exam information into the two RIS's. For one month, all patient information was entered into both the older RIS and the MDIS RIS. This provided extensive working experience for the various personnel and the opportunity for user errors to be detected and corrected prior to full dependence upon the new RIS. The functions used dually included patient registration, exam ordering, some transcription of radiographic reports and some reports approval by the radiologists and residents.

The transcription activities performed dually were minimal and rotated amongst the several personnel in the Radiology transcription pool. This dual entry of reports had to be kept to a minimum because of the extensive backlog which would have been established with full dual operations. Even short periods of transcription activity by the different transcriptionists was very important in furthering their training in the working environment. By rotating the "training" transcription activity through the personnel one person at a time, a trainer or supervisor could individually assist each transcriptionist in preparing for the upcoming full changeover to the new RIS. This period of experience and focused training facilitated a smooth transition.

The end result of reports processing is the final review and electronic signature of the report by the resident and staff radiologist. These personnel participated in the transition process also by having the duplicated reports sent to them on the two RIS's for review, any final editing and then signature and printing. Any individual problems encountered by any of these personnel were solved during this transition month, also. The participation of personnel ranging from the receptionists to the transcriptionists to the radiologists in this aspect of using two RIS's simultaneously for a relatively short period of time provided for a relatively easy transition.

Thus, overall, a fairly smooth transition was initially seen between the older RIS and the integrated RIS in the MDIS system. This was based upon successful training and continued hands-on training during a period of dual entry of information into both RIS systems while clarifying any operational questions that arose from any user during this training period.

Training

Introducing a new approach to Radiology operations into a functioning hospital is an immense enterprise, especially when the entire system is based upon automation. A tremendous range of experience in computer literacy may be found within the varied personnel in a large hospital Radiology department and in the users of the automation equipment outside of the Department. However, most personnel have some experience with automation equipment. But, this might not apply to all job descriptions within a department. Thus, the scope of the education and training issue can be seen in perspective.

A training plan was developed around a model known as instructional system development.[1] The core element of this model is the analysis of the jobs which various personnel will perform when interacting with a PACS system. This involves not only finding out what an individual does but also in what order he does his tasks, the conditions under which he operates and the level of performance of the tasks which is considered adequate for the job. The task list thus developed for each category of user then becomes the framework for the training. These learning tasks for each user group of personnel also comprise the list of terminal learning objectives. Plans of instruction are then developed to train the individual tasks for each user group to accomplish each of these terminal learning objectives. Some tasks are dependent upon learning other tasks and thus, these must be grouped together and ordered in a proper learning sequence (hierarchy) to allow for this progressive training to be accomplished.

The personnel to receive training were divided into several basic user groups. These included receptionists/schedulers, technologists, supervisors, file clerks, transcriptionists, radiologists and radiology residents and referring physicians. The tasks performed or to be performed by each user group were then enumerated. Not all functions of the system need to be trained to all users. One function may need to be trained in much greater depth to one group and only briefly or minimally to other groups. Thus, not only is there the need for the listing of tasks to be performed and trained to a given user group, but also the depth or quality of training required needs assessment. This is usually assessed by determining the level of performance required for an individual task.

A measurement of performance or testing of the trainees was also included in the Training Plan. This usually took the form of both a written test and a practical examination to assess the level of understanding of the tasks which the trainee had attained. All significant features taught to the trainee were covered in either the written or practical examination. These tests were also considered a method of feedback to the instructor(s) on their ability to teach individual concepts and tasks. If satisfactory

results were not obtained for an individual, then retraining in that particular area or function was performed, followed by retesting. This was repeated until a satisfactory performance level was obtained.

The instructional setting was typically two phased. Initially, system overview and then individual tasks were taught in a classroom in lecture format. Explanation of each individual system function as well as how a particular function related to other functions was given. Discussion and question-and-answer periods were included. After the didactic period, the classes were broken into smaller groups and the tasks were performed by the trainee at the terminal, workstation or other applicable component under the observation of the instructor.

Instructional material included overhead slides and 35mm slides. Handbooks and small reference cards with key commands were given to the trainee for his personal use after training. These proved quite useful for reference on how to perform specific tasks, particularly if the task was not commonly performed by the user.

A PACS system is comprised of many individual software applications and hardware components. The software applications to be trained were divided into various functional modules and then these were trained to the specific target user groups to which they were applicable. For example, patient registration and exam ordering were trained to the fullest depth to the receptionists and the technologists who would be performing this function either exclusively or at high frequency. Only the basic elements of this function were trained to the transcriptionist, the file clerk (who may use this when digitizing a film) and to the radiology resident (may use when assisting at night time or when digitizing a film for the Teaching File). this function was not taught to the Staff Radiologist or the referring clinicians. The major task groupings (modules) trained were patient registration, exam ordering, report processing (transcription, editing, approval and printing), film folder tracking, the workstation software (different levels of training for radiologists versus referring physicians) and specific training modules for individual pieces of equipment (computed radiography, laser printer/processor, video acquisition for ultrasound and the direct digital acquisition of CT, MR, Nuclear Medicine, and digital fluoroscopy devices).

Student selection was generally whomever was already occupying a specific position/function within the Hospital before the arrival of the PACS system. Fortunately, essentially all personnel had prior basic computer skills because of the pre-existence of the older RIS within the Radiology Department. Minimal computer skills were a prerequisite prior to proceeding with further training on specific applications. Self-paced tutorials were available for those without specific prior

familiarization with the particular platforms utilized in this PACS system. Basic computer literacy is becoming more prevalent in the working population but has not been a basic entrance requirement for some user groups to date, but this must be considered in the future, particularly with further advancements in automation becoming standard in the Radiology environment.

A training schedule was developed after identifying which training modules would be taught to which user groups, how many individuals were in each user group, training time required fro each group of learning objectives, and the availability of classrooms and instructors. Two instructors and two classrooms were used. The larger classroom, a conference room was used for large group didactic training, usually groups of 12-18 individuals. This classroom also had six RIS terminals set up in it to accomplish training of RIS applications to be taught to several user groups. Only one trainee per terminal was permitted for hands-on training on the RIS terminals. The other classroom had 3 workstations set up. Two trainees were trained at a time on each workstation in this classroom. The workstations were immediately adjacent to one another in this room so that the instructor could easily observe all students and immediately assist with any difficulties. The two students at each workstation observed each other performing each task as well as each performed all functions being taught.

Conclusions

Transition from one RIS system to another can be accomplished smoothly with adequate planning and training employed to facilitate this action. Overlapping of some RIS activity performed in a dual manner between the two RIS's provided real hands-on training opportunities and time for users to accommodate to differences between the two systems. This dual entry transition methodology for a short time did consume but the end result was a smooth transition. Existing electronic databases should be strongly considered for interfacing to the new RIS for downloading of the stored information acquired over the years on existing, active patient populations.

The entire staff of a large Radiology Department can be trained for their specific role in operation of a PACS system. Overall, this training plan development and implementation progressed smoothly.

Additionally, the commitment of clinicians from outside Radiology to undergo organized training on the workstations demonstrates their awareness of the powerful potential clinical tool which a PACS system represents. Indeed, beyond the actual development of the training course material, the most difficult challenge during training lay in scheduling physicians from outside the Department for their workstation

familiarization/training sessions which lasted for 1.5 hours after a 30 minute system overview lecture. This interrupted clinic and patient schedules to varying degrees and could have been felt as a negative impact in these areas where the clinical functions were impacted. Interestingly, the number of clinical users continued to actively grow after training of the first 120 clinicians, indicating that self-instruction or grief word of mouth instruction was proceeding successfully.

Adequate classroom (principally hands-on) equipment must be provided. This will usually involve the actual pieces of equipment installed for use and not separate training equipment. Physical space around this equipment for students and the impact n clinical schedules during training sessions must be included in the overall Training Plan.

Finally, feedback from the trainees is vital to the instructors and training developers so that assurance can be held that the instructional materials and methods are being employed in such a manner as to adequately train the student to the accepted level of competence in all his major tasks. This will result in the earliest clinical acceptance and utilization of the powerful clinical tool which a PACS system represents.

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The ideal teleradiology configuration from a physician's perspective

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ABSTRACT

Teleradiology systems are being developed and implemented around the world. The ultimate success of these systems depends on the acceptance by the end users - the physicians. From a physicians' perspective, several major areas need to be addressed in the ideal situation. The areas include (1) image quality and ease of manipulation of images on a workstation, (2) expert interpretation by a specialist or sub-specialist ,(3) good communication between the radiologist, radiology technologist, primary care physician, and the patient ,(4) accessibility to images , (5) system reliability, (6) costs and assistance in balancing workloads,and (7) education and research.

The Medical Diagnostic Imaging Support (MDIS) System is a large tri-service project to install Picture Archive and Communication Systems (PACS) and teleradiology at military medical treatment facilities across the United States and abroad. The first sites primarily involved with teleradiology will be installed in the summer of 1993. Ways in which the MDIS teleradiology system address the physicians' ideal configuration as well as possible future improvements will be discussed.

INTRODUCTION

The MDIS System is presently installing PACS and teleradiology sites throughout the military medical community. The MDIS contract was awarded as a joint venture to Loral and Siemens corporations in the Fall of 1991. The initial PACS sites are located at Madigan Army Medical Center in Tacoma ,Washington; Brooke Army Medical Center in San Antonio, Texas ; and Wright- Patterson Air Force Medical Center in Dayton, Ohio. Each of these sites will also function as teleradiology referral centers . The first site primarily concerned with teleradiology will be at Luke Air Force Hospital in Arizona . Luke will act as the center or "hub" for several other smaller sites or "spokes". Several U.S. military medical treatment facilities in Korea will also begin using teleradiology in the Summer of 1993 . Future sites include a large teleradiology project , "Akamai",connecting Tripler Army Medical Center in Hawaii with the Pacific basin and Korea. This teleradiology project will span 50% of the world's surface area.

The direct involvement of the end users is critical to the success of such a large project . Several areas of concern for teleradiology exist from a physician's perspective. Each of these issues will be discussed individually with an attached paragraph describing how MDIS addresses these concerns or future implementations needed to meet the ideal situation.

1. IMAGE QUALITY AND USER FRIENDLINESS OF THE WORKSTATION

For primary diagnosis from a workstation, the image quality should be at least as good as a conventional film/screen system. A recent teleradiology study in which digitized film/screen images were reviewed on a 2 K monitor workstation demonstrated that primary diagnosis can be made without review of the original plain radiograph [1]. Once developed, the high image quality must be maintained with a strict quality control program checking every link in the imaging chain to include computed radiography readers , film digitizers and workstation monitors.

The workstation must be user friendly and image manipulation rapid. To be user friendly, a system needs to be easy to learn for the beginner, but sophisticated enough not to hinder the experienced user. If the user does not feel comfortable, and avoids the system - all is lost. The workstation should be as fast as the conventional film/screen system for both the clinician and the radiologist.

Early experience at Madigan Army Medical Center on the 2K workstation monitors is encouraging ; to date there have been no known cases where a pathologic process has been seen on digital hardcopy film but not on the 2K workstation monitor. Two small studies done at Madigan indirectly support that the softcopy image is acceptable , but large ROC studies need to be done and are planned[2]. Several quality control procedures specific to a digital system have already been implemented; a comprehensive system is presently being designed by the MDIS project management office with help from outside academic institutions. Teleradiology can be used to assess the quality of images at multiple sites especially in remote areas. Presently, each location does its own evaluation of image quality (and this will continue) ,but frequently experts in assessing image quality are not available at small sites. It is too costly and time consuming to send an expert out to the multiple remote sites on a frequent basis. Images from all the teleradiology sites can be periodically accessed from the archive system and evaluated for image quality.

The MDIS workstation is quite user friendly . The Macintosh interface is easy to learn , but rewards the experienced user with the use of quick keys . The user friendliness of the system is reflected by the results of a survey of 75 clinicians at Madigan . Only 7% had received formal training (planned for the Summer of 1993 with installation of clinical workstations), yet 77% had already learned the basic functions on their own or with the help of a peer. The average time to learn the basic functionality of the workstation was stated to be 10 minutes. Of those who had learned to use the workstation , 100% stated that the workstation was useful and saved them time. In a separate study in which radiologists had to review large data sets , the workstation is presently slower than hardcopy film, but speed is expected to improve with new software releases in the Summer and Fall of 1993.

2. EXPERT INTERPRETATION BY A SPECIALIST OR SUBSPECIALIST

In remote areas, clinicians may have no practical way to have images reviewed by a radiologist. Nationwide, 30% of images are read by physicians other than radiologists [3]. Clinicians are sometimes forced to make serious treatment plan decisions based on their own interpretation of a radiographic finding. In the military air evacuation system, patients are occasionally flown to distant medical centers because of radiographic findings that are actually only variants of normal. Alternatively, some significant findings are missed and serious problems are not always addressed.

Radiology is a broad field with multiple imaging modalities that differ significantly ; it is becoming a sub-specialty profession. Ideally, all images should be reviewed by a radiologist and in some cases by a sub-specialist within radiology. Teleradiology allows for the development of "centers of imaging excellence" in various areas of radiology . All the images of one modality could be sent to a specific sub-specialty site for interpretation. For

example, all bone cases from several different spokes could be sent to a medical center with a group of experienced bone radiologists. This site may be augmented in the future with computer assisted diagnosis (CAD) for various bone pathologies. A sub-specialist is not only more likely to report the correct diagnosis, he can also review the images more rapidly than a general radiologist.This improves patient care and the efficiency of the radiologist. Large health care systems should exploit the resources available to them and maximize this potential.

As multiple teleradiology sites develop around the country and abroad, time zones can be used to an advantage. In remote sites there is often only one radiologist. It is not practical for him to be on-call seven days a week. Frequently, emergency room physicians read the images at night, then the radiologist over- reads the images the next day. With teleradiology, a patient being seen in a military hospital in Korea could have his image sent to the east coast of the United States to be read by a radiologist who is already awake and working. Also, when the radiologist is on-call, he would like to be able to read the images at home with access to any old images or reports from the database automatically.

With teleradiology, the clinician may not be as familiar with the radiologist. How does the clinician know if the radiologist at the other end of the teleradiology link is competent, or even board certified? Credentials will be more important than ever before. A stricter format to ensure the radiologist is competent will be needed. Presently many states only recognize radiologists licensed in their own state,therefore teleradiology communications across state lines pose a problem.

All MDIS referral centers can receive teleradiology images. The MDIS sites span from Korea to the Azores (off the coast of Portugal), so using time zones to an advantage is possible and will be tested beginning in late 1993. Since the MDIS system involves the U.S. military, cooperation exists among multiple sites. Sending images to a sub-specialist instead of a general radiologist can be done. Testing of this concept on a small scale is planned for the Fall/Winter of 1993. On a national scale, some logistical problems with workload accounting and the home of record for the image and report are being worked out. Centers of imaging excellence are only in the planning stages. In the military, the issue of credentials and interpreting images across state lines is somewhat easier because a military radiologist only has to hold a single state license.

3. GOOD COMMUNICATIONS

Maintaining good communications between the clinician, radiologist, and the patient is vital to good patient care. Communication begins with the radiologists' ability to review the patient's clinical history; then, the radiologist's dictated report must be available quickly with easy access to the clinician. Finally, the clinician and radiologist must be able to consult on a specific case when necessary. Having a radiology information system(RIS) at all teleradiology locations is very useful. The radiologist can access the patient's clinical history and old reports electronically. Images can be tied to the dictated report.

If the dictated report is not immediately available (wet read) then the clinician must at least be able to see the image himself during the same patient visit. In most cases, a 24 hour turn around time is acceptable, but there must be a way to prioritize an image as "STAT emergency", so that it can be sent and reviewed before other images taken earlier in the day. Presently, at several remote sites, radiologists review the images once or less per week; therefore, the turn around time for reports is extremely slow. For a small site, the STAT case could be reviewed at the hub and the initial answer returned by handwritten fax or a telephone call with a typed report to follow. For a larger site that has diagnostic monitors, a voice captured response tied to the image could be used. A written report would follow. A speech recognition system for dictating reports is appealing. This eliminates the need for transcriptionists and decreases the time to get a typed report to the clinician. A speech recognition system could also eliminate the need for a voice-captured or handwritten Fax report.

Recently this issue has come to the forefront in the medicolegal arena. The American College of Radiology came forth with a set of guidelines called Resolution 5 supporting the concept that the radiologist is responsible for making sure the clinician knows the results of an imaging study if it is abnormal [4]. An E-mail system is useful to help notify clinicians of a positive finding and document that the report was received.

With teleradiology, the close working relationship between the clinician and the radiologist is at risk. Traditionally, the clinician gets to know the individual radiologist over time. The clinician learns how much he can rely on a specific radiologist to be correct. Does the radiologist over or under call pathology? These factors are taken into consideration by the clinician when deciding a patient's treatment plan. A direct phone line (1-800 number) between the clinic and the radiologist is needed so a clinician can easily discuss a problem case with the radiologist. New teleconferencing software has recently been made commercially available with audio and visual capabilities which allow the clinician to call the radiologist and discuss a case real-time via a small window on the workstation screen . The clinician and radiologist can be consulting with each other and seeing the patient images at the same time. This is a key breakthrough in protecting the radiologist/clinician professional working relationship.

The interaction between the radiologist and the radiology technologist is important as well; this would be another use for teleconferencing software. A "teleradiology site" coordinator who is accountable for all teleradiology images and can act as a point of contact for the outside clinicians would also be useful.

All MDIS sites will have a radiology information system tying the spoke and hub together. "Wet " readings will be available as needed. Direct phone lines and Fax communications will be used initially. With the MDIS workstation, the clinician and radiologist can be in different locations and be looking at the same patient's images at the same time. Speech recognition and teleconferencing systems are presently being evaluated and are expected to be available. Teleradiology hubs will have a designated "Chief of Remote Diagnosis " to coordinate the interactions between the hub and its' spokes.

4. ACCESSIBILITY OF IMAGES

In general, one of the great strengths of a digital system and the justification for installing it , is the improved accessibility of images. Therefore , it is critical that images be at least as accessible as a conventional film/screen system to all clinicians, radiologists , and patients. The clinician needs the ability to send some cases "STAT" to be reviewed by the radiologist and returned immediately . With dial up T1 lines , an image can be transmitted in about 30 seconds if necessary. In most cases , a "STAT" report is not needed , and a turn around time of 24 hours is acceptable. In these routine cases ,it makes sense to send the studies in batch overnight when there is less traffic on the telecommunications system and commercial rates are cheaper. In order to batch a large number of studies together, a storage media at both ends is required.

A clinician ideally wants to see the image and the dictated report together on the same screen. The clinician needs to be able to review the images with his patient or other clinicians outside of the radiology department. If a family practice doctor has to explain to a 20- year old that he has a tumor in his leg requiring him to transfer to a major medical center for amputation,the physician needs to be able to show the patient the image to convince him that both the trip and the surgery are necessary. At a small spoke , archiving images seems most cost effective using hardcopy film ; multiple monitors throughout a group of clinics would not be cost effective. At larger spokes, either monitors in the clinics or hardcopy film could be used based on the size of the site. It is necessary to be able to print a hardcopy film at the spoke in cases where the patient is to be transferred to an outside hospital. In general, it is good to have the

teleradiology spoke connected with its usual tertiary care referral hospital.In this way, patients to be transferred will already have their images available to clinicians at the referral hospital. The clinicians can review the case and discuss surgical planning even before the patient arrives.This can be especially useful in emergency cases where immediate intervention is needed.

For the radiologist to make meaningful interpretations at the hub, a protocol is needed to transfer historical images for comparison . In Korea, many people have signs of tuberculosis on their chest x-ray . It is difficult to distinguish between acute and chronic disease without old films. Protocols for chest x-rays might include the images just done, the most recent old films and a chest x-ray greater than two years old.

The MDIS system utilizes dial up T1 lines with all of the advantages mentioned earlier. The workstation allows the clinician to review the image and report on the same screen. The image of record at small spokes will be hardcopy film where as large spokes will archive images digitally. Protocols for digitizing comparison images need to be developed.

5. SYSTEM RELIABILITY

When teleradiology is the sole mode to support imaging for a medical treatment facility, the reliability of the system directly affects patient care. The system must be extremely reliable. If the communications link goes down, the system must be able to still function; storing images and then sending them later when the communications return is required. The personnel running the system must also be reliable. A strong training program for all personnel involved is critical. This is especially true in remote locations. At large medical centers, if an individual does not learn a function on a computed radiography unit, he can ask one of his peers or on -site vendor experts. In a remote area, this option may not be available. Unless training is outstanding ,there is a risk for personnel to follow incorrect procedures. This can easily lead to bizarre artifacts. A group of experts is needed to troubleshoot problems as they arise . Maintenance of the equipment is another important issue, especially in remote areas and foreign countries where support may be difficult.

Although no teleradiology sites in the MDIS system are yet operational, Madigan hospital has the same basic equipment. In the first 10 months ,the system up -time was >98% (99.7% when the facility air conditioning problem is excluded). The MDIS teleradiology system can accommodate a breakdown in the communications link and still function by storing images and then sending them later when the communications return . A group of 10-12 experts including physicists, engineers, communications specialists, computer specialists, an MBA, a radiology technologist , and a radiologist are available to support the various sites and troubleshoot problems as necessary. Eight year maintenance contracts are available and a revised intensive training program has been developed.

6. BALANCING WORKLOADS

The military has multiple small medical treatment facilities (similar to rural America), some in very remote sites. Although many of these sites have low workloads(less than one radiologist equivalent), they require radiological support. Some sites do imaging studies such as ultrasound and gastro-intestinal (GI) barium fluoroscopy exams which require the physical presence of a radiologist on- site. The military has a shortage of radiologists. Civilian radiology contracts in the military are expensive. The military has a difficult time finding civilian radiologists to cover remote sites. These remote sites are frequently unpopular with military radiologists because often only ordinary x-rays are available with no computer tomography(CT), or magnetic resonance imaging(MRI); therefore, the radiologists' skills deteriorate in these areas.

The MDIS solution to this problem is two- way teleradiology transmission of images.

In locations that support ordinary x-ray, we can send images via teleradiology to other sites and save the cost of a civilian contract radiologist. At a site where a radiologist must be present (due to special procedures) but has a low workload, we can send him additional studies to read thereby maximizing his utility. Traditionally, sites with only one radiologist get into trouble when the radiologist is on vacation , sick leave ,or temporary duty. Now studies can be sent to another site via teleradiology and elective procedures such as GI fluoroscopy can be delayed for a few days.

The military ,with the ability to send any image, anywhere, can start to place radiologists in their desired location thereby improving radiologist's satisfaction. A radiologist at a remote site can receive images not normally available (CT and MRI) to maintain his skills. Another workforce that can be potentially utilized are our radiologists in the Army, Navy, and Air Force Reserves. They could go to a location nearby their home, and read x-rays sent to them via the two- way transmission teleradiology system. The challenge to the military now is to harness the advantages of two-way teleradiology.

7. EDUCATION AND RESEARCH

The ability to use two -way transmission to maintain the skills of radiologists in remote sites has been discussed. Additionally , peer review of image interpretation is a requirement to ensure standards of quality are maintained. Teleradiology makes peer review of images a relatively simple process. Images that have already been read at one site can be sent to another for a second interpretation. Disparity of interpretation can be reviewed and settled by an accepted expert within the teleradiology system. Alternatively, a standard set of images can be sent to all sites for interpretation by their perspective radiologists and then this data evaluated. Individual radiologists with demonstrated weaknesses in an area can be given follow -up training as needed. In this way , a large system like the military can maintain quality control standards and correct weaknesses through follow -up training.

Since the central hub acts as a large archival center already, it can store a set of teaching images. Anytime a teleradiology site has an interesting case, it can send the images to the hub for archiving such that users at other sites can access the images for review. This concept could be done at the local or national level.

The MDIS program will have as many as 21 teleradiology sites by 1995 . We hope to test the concept of a peer review teleradiology system in 1993 . The potential in terms of imaging pathology for education and research is impressive and needs to be harnessed. Databases for each hub and its spokes will be in place and the ability to send any image to any MDIS site will be possible . The logistics of a national database still need to be worked out and implemented.

CONCLUSION

Physicians should be involved in the decision making process for a teleradiology system and in the development of new options the technology provides. A teleradiology system needs high image quality and a user friendly interface, qualified radiologists interpreting images, close communications between the clinician, radiology technologist, and radiologist, images rapidly accessible to the clinician with a dictated report tied to the image, a highly reliable system with the freedom to shift workloads as necessary, and the ability to utilize a large database of images for education and research purposes.

Although the MDIS configuration does not presently include all of the features ideally desired, we are working towards this goal. The MDIS plan has several innovative ideas such as two -way transmission of images, combined teleconferencing ability, use of time zones to maximize resources, centers of imaging excellence, and the concept of a "Chief of Remote Diagnosis" to coordinate the teleradiology efforts. The goal is to harness the great potential of

teleradiology to realize cost savings, improve patient care, and increase the satisfaction of both the clinician and radiologist.

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Evolution of teleradiology in the defense medical establishment

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1. INTRODUCTION

The Medical Diagnostic Imaging Support (MDIS) System is a four-year contract to install large-scale Picture Archival and Communications Systems (PACS) and Teleradiology in Army and Air Force Medical Treatment Facilities. MDIS specifications were based on the results of three years of tri-service research and development through the Digital Imaging Network Systems (DINS) Project and the Tactical Air Command (TAC) Teleradiology Project. At the time of the government's Request For Proposals (RFP), MDIS functional specifications represented the most comprehensive understanding of the requirements for large-scale PACS andTeleradiology compiled by a composite team of radiologists, physicists, clinical engineers, hospital administrators, technologists, and computer systems engineers. As MDIS sites become operational, a better understanding of the capabilities and limitations of Teleradiology is emerging.

This paper will review functions and subsystems common to all Teleradiology systems, MDIS specifications for Teleradiology, installation planning, and the status of Army and Air Force Teleradiology with special emphasis on early installations that will validate routine Teleradiology operations.

2. RESEARCH AND DEVELOPMENT OF TELERADIOLOGY

The Defense Medical Establishment (DME) has been actively interested in teleradiology for a number of years. Both the Army and Air Force have conducted successful demonstrations of Teleradiology in conjunction with disaster relief efforts, combat medical care, and peacetime health care under remote and adverse conditions. MDIS Teleradiology programs are derived from several successful development and demonstration projects, including the Tactical Air Command (TAC) Teleradiology Demonstration Project, the Army Digital Imaging Network Systems (DINS) Project, the Strategic Air Command (SAC) Teleradiology Project, Army disaster relief efforts following Hurricane Hugo, and Battlefield Teleradiology during Operation Desert Storm.

2.1. TAC Teleradiology Demonstration Project

In January 1989, ordinary x-ray images were acquired and digitized by the 4th Medical Group at Seymour Johnson AFB, NC and transmitted via commercial telephone lines for diagnosis to the 832d Medical Group at Luke AFB, AZ[1]. Diagnosis by Teleradiology was then compared to primary diagnosis from film. Cases included upper extremities, head, and cervical spine studies 8"X10" format. For 4 of 58 images, diagnosis could not be made by Teleradiology, one because the fracture was not within the active area of the digitizer, and three because of inadequate dynamic range of the digitizer. Of the 54 remaining cases, diagnosis by Teleradiology matched diagnosis made from film in all cases, which were a mix of normal and pathological. This brief demonstration convinced the Air Force that even with primative equipment and slow transmission speeds, clinically useful images could be acquired at one facility and transmitted to another for diagnosis.

2.2. DINS Project

The DINS Project was a 3 year (1987-1990), $19 M project to install a Picture Archival and Communications System (PACS) at Georgetown Medical School Hospital and the University of Washington[2,3]. The purpose of this effort was to better define the technical requirements for PACS, to determine whether technology was adequate to support those requirements, and to advance the level of digital imaging technology where possible. The project was managed by MITRE Corporation, and included efforts to define the role of digital imaging on the battlefield, such as development of a ruggedized high capacity x-ray generator (Picker), a prototype compact computed tomography (CT) device (IMATRON), a battlefield Computed Radiography (CR) scanner (Phillips), a Soldier's Individual Radiology Record on electronic media, and a digital network of workstation for a field hospital. This project encouraged improvements in digital medical imaging products and convinced Army Medical leadership of the value of PACS in peacetime health care settings as well.

2.3. SAC Teleradiology Project

In late 1990, the Air Force installed an AVP teleradiology system to acquire images at 319th Medical Group, Grand Forks AFB, North Dakota and transmit them to the 5th Medical Group, Minot AFB, North Dakota for diagnosis by a radiologist The system replaced an underutilized Air Force radiologist formerly assigned to Grand Forks AFB. Operation of the syste eliminated the practice of evacuating patients from Grand Forks AFB to Minot AFB for radiology exams which previous occurred during temporary absences of the radiologist. This Teleradiology system is still in routine operation today.

2.4. Hurricane Hugo Relief

When Hurricane Hugo devastated the Virgin Islands in March 1990, the 119th Mobile Army Surgical Hospital (MASH) from the Alabama Army National Guard deployed to St. Croix. Along with the 119th MASH, the Army Medical Department sent the prototype Battlefield CR scanner, a digitizer, and an International Maritime Satellite (INMARSAT) terminal. Images were acquired in the Virgin Islands and transmitted via satellite to Walter Reed Army Medical Center in Washington, D.C. and to Dwight D. Eisenhower Army Medical Center in Augusta, Georgia. This relief effort demonstrated the value of deployable teleradiology systems.

2.5. Operation Desert Storm

In support of Operation Desert Storm, Project MedCAT deployed two midrange commercial CT scanners to Saudi Arabia and set them up with Army Evacuation (EVAC) hospitals in the combat zone[4]. A commercial video frame grabber product (GE; Images-on-Call) was connected to one of the CT scanners. Using an INMARSAT terminal, CT images were transmitted from the desert via the Indian Ocean Satellite and the International Telephone Network to Brooke Army Medical Center in San Antonio, Texas for expert consultation. Although the primary purpose of Project MedCAT was to provide CT on the battlefield, this demonstration showed the value of Teleradiology in combat operations.

3. INCENTIVES FOR TELERADIOLOGY

Interest in Teleradiology within the DME arises from diverse motivations. Incentives for Teleradiology can be stratified into organizational benefits that are primarily administrative, benefits for either the radiologist or clinician, and benefits to the patient through convenience or improvements in quality of care. Table I. is an attempt to summarize benefits that might be expected from Teleradiology. Each entry might constitute the sole reason a facility decides to use Teleradiology. Realization of the expected benefit may or may not occur. This concept is important in determining the success of a Teleradiology implementation, especially in a Total Quality Management (TQM) environment where quality may be defined as "meeting the customer's expectations" rather than strict cost/benefit.

Emphasis on a specific set of benefits can drive the design of the Teleradiology system to a unique engineering solution. For example, a system designed primarily to redistribute workload from one medical treatment facility (MTF) to another may not facilitate interactions between the radiologist and the clinician. A system intended to efficiently transfer workload may not necessarily improve turnaround on the radiologist's interpretation unless this is also emphasized in the design.

When problems that served as the initial stimulus for Teleradiology are resolved, focus often shifts to secondary benefits that may or may not be provided by the engineering solution. For instance, a critical shortage of uniformed radiologists was a primary influence in the development of DME Teleradiology. This shortage was partly alleviated by Base Reallignment and Closure (BRAC), new military radiology residency programs, and aggressive recruiting. Where it is possible to staff a remote site with a military radiologist, the emphasis shifts to supporting the radiologist by providing continuity of coverage, expert consultation, Continuing Medical Education (CME), and workload sharing with other MTFs. The engineering solution to meet these needs involves more sophistocated two-way image transmission than *a* basic uni-directional concept. A Teleradiology system based on total transfer of workload will be largely underutilized when the remote spoke is staffed with a radiologist. Workstation design is also more demanding at a site where routine primary diagnosis is to be performed on soft copy images.

Benefits such as decreased film costs, decreased file space, and decreased file room personnel are realized primarily in Teleradiology sites that utilize computed radiography (filmless imaging); however, copy film costs can be recovered if original images are digitized instead and transmitted to a referral center. Likewise, the decreased retake rate and lower patient exposure normally associated with computed radiography can be achieved in part by better availability of historical images from digital archives.

Just as the value of benefits can be more for one beneficiary group than another, a benefit for the remote spoke can result in an inconvenience for the central hub, and*vice versa*.. Recovering contract radiologist costs at a spoke by transferring workload to a hub is a benefit for the spoke, but an increase in workload at the hub. Receiving workload from a spoke might be perceived as a benefit to the hub compared to providing a "circuit rider" to the spoke, but the spoke may prefer the actual presence of a radiologist, even if only on an intermittant basis.

In some cases, the introduction of Teleradiology technology reveals shortcomings in the healthcare system that were previously not apparent. For example, ready access to approved reports by clinicians might highlight a backlog in transcription or report approval by the radiologist. This is described in Management literature as the "Hawthorne Effect".

It is possible that the most important benefit of Teleradiology is its contribution to regionalization of health care. A robust Teleradiology system allows a small number of radiologists to provide services to a larger group of clinicians in a given region.

TABLE I. ANTICIPATED BENEFITS OF TELERADIOLOGY

Expected Benefit	Beneficiary (Organization/Clinician/Radiologist/Patient)
1. Recovery of Contract Costs	
a. Radiologist Authorized but not Assigned	ORG
b. Radiologist TDY, Leave, and underlap coverage	ORG/CLIN/RAD/PAT
2. Workload redistribution	ORG
3. Improved evacuation and referral decisions and coordination	ORG/PAT
4. Decreased film and chemical cost	ORG
5. Improved clinician and radiologist productivity	ORG
6. Reduced film file space	ORG
7. Reduced film file staff	ORG
8. Facilitated regionalization of health care	ORG
9. Improved retention of all providers	ORG/PAT
10. Improved film management	
a. rapid access to film files	ORG/CLIN/RAD
b. fewer missing films	ORG/CLIN/RAD/PAT
11. Decreased retake rate	PAT
12. Decreased patient exposure	PAT
13. Radiologist involvement in diagnosis and treatment plan	CLIN/RAD/PAT
14. Improved turnaround on radiologist interpretation	CLIN/PAT
15. Radiologist CME	
a. multi-modality for remote assignments	RAD
b. more direct involvement in patient care	CLIN/RAD/PAT
16. Access to expert consultation	
a. radiologist for remote clinician	CLIN/PAT
b. second opinion for radiologist	RAD/PAT
c. subspecialties at tertiary care centers	CLIN/RAD/PAT
d. subject matter experts at AFIP	CLIN/RAD/PAT
17. Opportunity to provide subspecialty consults	RAD
18. Screening to avoid unneeded return to hospital	RAD
19. Cross coverage for Radiology "call"	RAD/ORG
20. Enhanced radiologist morale	RAD/ORG

4. MDIS TELERADIOLOGY

The Medical Diagnostic Imaging Support (MDIS) System is a four year, indefinite delivery, requirements contract to install turn-key PACS in Army and Air Force Medical Treatment Facilities (MTF) worldwide[5,6]. Other government agencies such as the Navy and the Veterans Affairs (VA) can purchase PACS using the MDIS contract. The prime contractor is Loral Western Development Laboratories teamed with Siemens Medical Systems. MDIS installations already in progress include Madigan Army Medical Center in Tacoma, Washington, Wright-Patterson Air Force Base in Dayton, Ohio, and Brooke Army Medical Center in San Antonio, Texas[7].

MDIS includes both intra-MTF PACS and Teleradiology. The MDIS contract defines Teleradiology as large and small spokes connected to small, medium, and large hubs[8]. Tables II. and III. distinguish spokes and hubs by workload and functionality. A small spoke produces as many as 100 images per day with no radiologist on-site. A large spoke produces from 150-300 images per day, and sometimes has a radiologist present. Image communication between hubs is also supported. MDIS intra-MTF sites also function as Teleradiology hubs.

TABLE II. CHARACTERISTICS OF GENERIC SPOKES

	Workload*	Input	Display & Output
Small Spoke	30-100/day	Small Film Digitizer and Desktop CR	Single Screen SCID-O
Large Spoke**	150-350/day	Large Film Digitizer*** and Mid-perf. CR***	2 Screen SCID-S

Notes: * 14"X17" image equivalents
** also receives images from hub
*** includes preview monitor

TABLE III. CHARACTERISTICS OF GENERIC HUBS

	Input Spokes	Display & Output	Storage	Image of Record	
Small Hub*	4 small or 1 large	2 Screen SCID-S	Magnetic or Erasable Optical	Hardcopy film and report at spoke	
Medium Hub*	4 small or 2 large	2 Screen SCID-S	Single Drive Optical Disk	On disk at hub	No RIS
Large Hub*/**	8 small or 4 large	two each 4 Screen SCID-S	Optical Disk Juke Box	On disk at hub	RIS Support

Notes: *upgradeable to 8 spokes
**capable of transmitting images to spokes, upgradeable to intra-MTF PACS

4.1. Planned MDIS Teleradiology Sites

Air Force first-year MDIS installations include six large Teleradiology spokes and six small spokes transferring images to one medium hub, two small PACS sites, and one large PACS site. Year-one Army sites include one deployable small spoke transferring images to a small PACS site, one fixed and one deployable small spoke transferring workload to a large hub with a consultation link to a tertiary care center, and two small spokes transmitting images to a large PACS facility.

4.1.1. Hilltop Plan

Hilltop is the plan for initial implementation of Teleradiology for the U.S. Air Force. The Hilltop Plan consists of four Teleradiology constellations. Luke AFB (Phoenix, AZ) will serve as a hub for large spokes at Davis-Monthan AFB (Tuscon, AZ), Mountain Home AFB (Mt. Home, ID), Cannon AFB (Alamagorda, NM), Holloman AFB (Clovis, NM), and Dyess AFB (Abilene, TX). Luke itself will be a small PACS site. Spokes in the second Hilltop constellation will use the medium PACS site atWright Patterson AFB as a hub. These include K.I. Sawyer AFB (Marquette, MI), Griffiss AFB (Rome, NY), Lajes AFB (Lajes, The Azores), and McConnell AFB (Wichita, KA). Because the permanent facilities at McConnell were destroyed by a tornado, this spoke will be operated from an Air Force x-ray ISO Shelter. The ISO Shelter is a module from an Air Transportable Hospital. The third constellation consists of a large spoke at Fairchild AFB (Spokane, WA) and a small spoke at McChord AFB (Tacoma, WA) feeding images into the large PACS site at Madigan Army Medical Center (Tacoma, WA). Hilltop also includes spokes at Osan AFB and Kunsan AFB, that are the Air Force's portion of the Teleradiology system for U.S. Forces Korea. Site visits have been conducted at all Hilltop sites with the first sites expected to come on line in Spring of 1993.

4.1.2. U.S. Forces Korea

There are 17 U.S. military medical treament facilities scattered about the Republic of Korea, an area roughly the size of Indiana, to provide health care for approximately 40,000 U.S. troops and their dependents. Only one Air Force and three Army radiologists are assigne to provide radiological diagnosis. An extensive Teleradiology network, nicknamed "Daybreak", is being installed to link remote Troop Medical Clinics with larger hospitals located at Osan and Yongsan[9]. Present delivery orders include small spokes at the Air Force 8th Medical Group, Kunsan , and Army Camp Walker, Taegu connected to a medium hub at the Air Force 51st Medical Group, Osan, and a large hub at the Army 121st EVAC Hospital, Yongsan. These sites should become operational by Fall 1993. Near term plans include additional spokes at Army Camps Casey (Dongduchun), Red Cloud (Uejungbu), and Humpherys (Pyongtaek) with a small PACS system at Osan and Yongsan. Ultimately, all medical treatment facilities on the penninsula will be part of the Teleradiology network. Image and text communications are passed at T1 speeds over an existing U.S. government-owned fiber optic network. A Teleradiology referral and consulation link will be established between the 121st EVAC Hospital and Tripler Army Medical Center in Oahu, HI.

4.1.3. DDEAMC

Dwight David Eisenhower Army Medical Center (DDEAMC, FT Gordon, GA) will act as the diagnostic hub for images produced at the U.S. Army Health Clinic at FT McPhereson, GA. DDEAMC will have a small, intra-MTF PACS. The spoke hardware will be located in a standard Deployable Medical System (DEPMEDS) x-ray ISO (International Standards Organization) Shelter at FT McPhereson.

4.1.4. AKAMAI

The AKAMAI Health Care Project is a proposed five-year project linking Pacific Rim military clinics to Tripler Army Medical Center (TAMC; Oahu, HI). *Akamai*, meaning "smart" or "clever", includes a filmless medical imaging system using MDIS technology at TAMC and a research, development, testing, and evaluation site at Georgetown University Medical Center (Washington, D.C.). AKAMAI will link spokes throughout the Pacific Rim. The spokes include clinics in Japan (Misawa, Yokota, Kadena, USN Camp Lester), Alaska (Elmendorf AFB, FT Richardson, Eielson AFB, Bassett Hospital and Guam (Anderson AFB Clinic, USN Hospital), as well as the Korea Teleradiology system (see 4.1.2. above). Spokes in the Mid Pacific, include Hickam AFB, Kanehoe Clinic, Makalapa Clinic, Barbers Point, Wheeler Army Air Field Clinics, Schofield Barracks, Barking Sands, Kahoolawe Clinics, Midway Clinics, Wake Clinics, Johnson Atoll Clinic, Camp Smith Clinic, and Fort Schafer Clinic. The central hub at TAMC will be linked to a consultation center at Georgetown. Funding for the first year of AKAMAI has been authorized.

4.1.5. Lone Star

MDIS Teleradiology for the Brooke Army Medical Center (BAMC) Region will provide support between BAMC hub (San Antonio, TX) and remote sites (spokes) at Fort Hood (Killeen, TX), Fort Polk (Leesville, LA), Fort Sill (Lawton, OK), Gorgas Hospital and Howard AFB (Panama), Task Force Bravo, Honduras, Corpus Christi Naval Air Station (TX). Remote site Radiology departments will primarily use soft copy diagnosis from both digitized film and computed radiography, and will have the capability to send and retrieve images from the BAMC hub. BAMC will interpret referred images from remote sites, provide consultative and educational support, and optically archive all images sent by sites. Task Force Bravo, Honduras, will be installed in a standard x-ray ISO shelter and will include a 56 Kbps satellite ground station for use over INMARSAT or military satellite systems.

4.2. Functional Description of Basic MDIS Teleradiology

Any Teleradiology system has a set of fundamental functions that must be accomplished to enable the practice of Radiology at a distance[10]. How the system is engineered to accomplish these functions determines system performance, operator interface, and cost. The sections that follow describe how MDIS addresses these functions for Teleradiology operations.

4.2.1. Acquire images and associated patient information in digital form.

MDIS includes a variety of methods for acquiring images in digital form, including film digitization , computed radiography (CR), video capture, and direct digital interface. For Radiology departments at spokes, the primary (and sometimes exclusive) imaging modality is ordinary x-ray. MDIS provides CR and film digitizer capabilities at spokes. Image resolution is basically 2K X 2K pixels by 10 bits gray scale deep for a 14" X 17" image. The decision to use CR or remain film-based depends on specifics of the spoke such as workload, logistics, economics, and the technical sophistocation of the staff. Other modalities could be incorporated by direct digital or video capture, including CT, MR, Nuclear Medicine, and US. It is important to note that the image quality for remote diagnosis is more demanding than for remote consultation. Local display (preview) monitors are provided for initial QC for positioning and technical errors, but do not display the full data set. Patient and study information are manually entered by the technologist as the image is acquired in digital form. The request for interpretation is annoted to indicate whether a "STAT" report is required.

4.2.2. Transmit image and associated patient information to hub.

MDIS can transmit digital images over a variety of communications methods including commercial dedicated high speeed lines, high speed digital switched networks, and "fract-dialing" (access of n X 56 kbps of bandwidth up to T1 speeds)[11]. The transmission method should not degrade image quality. The transmission mode is selected from services available for the spoke isdetermined by image size, workload, transmision speed, and acceptable turnaround time. The MDIS contract requires that the selected method be capable of transmitting an average day's workload in 3-4 hours. To minimize transmission time, images are compressed before transmission by a 2:1 reversible compression algorithm (lossless). Lossless compression is required by MDIS for images transmitted for remote diagnosis. Higher order (lossy) compression is acceptable for images that have already been interpreted by a radiologist and are transmitted for remote consultation.

4.2.3. Receive, store, schedule for interpretation, and ultimately archive images

As each image arrives at the hub, it is automatically archived to optical disk. While the full-resolution image remains in the hub's local memory, a compressed copy of the image is created by a modified JPEG discrete cosine transform (DCT) compression algorithm to about one-tenth of its initial size. Images are assigned to an individual radiologist's worklist according to configuration-specific rules for dividing workload. STAT images are routed to a special "Wet Desk" worklist for immediate attention.

4.2.4. Transfer images to radiologist; display and manipulate image at hub.

A Radiologist at the hub displays images and patient information for softcopy diagnosis on a diagnostic workstation (standardized workstation; SCID-S). The full image data set is available at all MDIS workstations. Diagnostic workstations can be configured with 2K X 2K monitors or with lower cost 1K X 1K monitors. Workstations with the lower cost monitors initially display a downsampled set of the image data, but can zoom into the full data set. A variety of diagnostic tools are available to the radiologist including adjustment of "window" and "level" similar to CT. The number of monitors on diagnostic workstations usually varies from two to four, although a single screen SCID-S can also be configured.

4.2.5. Dictate, transcribe, and transmit report to spoke.

The radiologist at the hub dictates findings using the department's conventional dictation system. If he chooses, he can manually enter the report into the MDIS Interim Radiology Information System (IRIS) from his diagnostic workstation. Otherwise, the transcriptionist inputs his report into the IRIS from a RIS terminal. The report is then available to the radiologist for review and approval. The system can be configured to support additional levels of overreading and approval, as practiced by a department with a radiology residency program. Once the report is approved, it is automatically transmitted to the spoke. The electronic version of the report is attached to the image and archived at the hub. The full resolution image is now available for deletion from the hub local on-line storage. STAT requests are read immediately upon receipt and the results are relayed to the referring physician telephonically.

4.2.6. Receive and distribute report at spoke.

Reports are automatically received and printed in three copies at the spoke. The spoke radiology department manually distributes reports to the provider/requester, the patient record, and the radiology record.

4.3. Augmented functions of MDIS Teleradiology

The functional description above adequately describes a film-based digital teleradiology system where the primary purpose is to shift workload from a spoke to a hub in the simple case where no radiologist is present at the spoke. When images are acquired directly in digital form or when a radiologist is present, the functional requirements of the system must be modified to support additional clinical operations at the spoke. In this case, the system is required to support more sophistocated operations at the spoke. Normally, the level of sophistocation of a Telemedicine system *decreases* with the level of training of the health care provider at the spoke, because the remote provider filters the diagnostic information before he passes it to the hub.

4.3.1. Support of radiologist at spoke

When a radiologist is present at a spoke, it may be desirable to share workload from the hub to the spoke. In this case, additional functions of transmitting images from the hub and receiving them are required, as well as the requirement for a diagnostic soft-copy workstation (2KX2K) and the capability to input reports from the spoke.

4.3.2. Digital acquisition at spoke

When images are acquired initially in digitial form (computed radiography, computed tomography), distribution of the images to clinicians within the spoke is an additional fundamental function. While it is possible to make a hard copy for every exam , this practice erodes the cost/benefit of CR (single emulsion laser film is slightly cheaper than double emulsion film). There are several ways to accomplish this function.

Clinical workstations (optimized workstations; SCID-O) can be added to the Ethernet that connects the components of the large spoke. This approach involves some decrement in performance for the rest of the system.

Loral/Siemens is developing a new file server called a "micro-working storage unit"(micro-wsu). This file server wi'' incorporate the star topology fiber optic network used in MDIS PACS facilities for large Teleradiology spok(Incorporation of the micro-wsu effectively makes the large spoke a "mini-PACS".

A third, less expensive, low technology system is to drive slave video monitors
from workstations in Radiology. Clinicians would call Radiology and ask for a particular patient's exam to be displayed. This approach has several disadvantages. The patient's image is broadcast to all slave monitors unless a video switch is installed. The image quality of the video monitor is inferior to the clinical workstation. Finally, the image on the slave monitor cannot be manipulated by the clinician to enhance clinical features.

As an alternative to distributing the images on a network, a patient's images could be copied to removeable electronic media (optical disk, streaming tape). The media could be carried to the clinician who would load it into a clinical workstation operating independently from the rest of the system. This approach is less expensive than the micro-wsu, but still requires the purchase of clinician workstations.

The minimum-cost solution is for the clinician to walk down to Radiology and view images on a workstation there. This approach is practical only where the workload is low and where the clinicians are located no farther than a convenient distance from the Radiology department.

4.3.3. Hard copy at spoke.

Until whole medical world is digital, there will be a need to produce hard copy images to accompany patients that are referred or evacuated outside the MDIS hospital. Until digital technology improves, mammography will be acquired on film. It's probably not cost effective to provide video interfaces at spokes: typically ultrasound images will be printed on film. Some of the expense of printing film can be averted by designing teleradiology constellations around referral patterns. This practice would also contribute to the regionalization concept, where tertiary care centers act as managers of health care within a geographic region.

4.3.4. Offsite transcription.

At many MTF's today, transcription services are provided by offsite contractors. For the MDIS Teleradiology system to be effective, transcriptionists must have the ability to remotely access the IMS system to update reports. Commercial voice-grade telephone lines are adequate for this purpose because the data rate is limited by transcriptionist typing speed.

4.3.5. Portable teleradiology.

MDIS includes the capability for portable workstations that can access images away from the MTF site. Like an offsite transcriptionist, a radiologist needs to be able to access the IMS via dialup for emergency call. Unlike offsite transcription, data rates attainable on commercial voice grade telephone lines are inadequate for routine image traffic. Dialup 56 kbs service and incremental 56kps up to T1 rates are available. Initial installation costs for these services are a drawback of portable Teleradiology.

4.3.6. Deployable teleradiology.

The MDIS contract includes an option to augment a Teleradiology spoke with a portable L-band satellite terminal to transmit images from locations without telecommunications utilities (see 2.4. and 2.5. above). The transmission speed of the commercial INMARSAT system is limited by current technology to 19.2 kbps duplex using voice channels and 56 kbps for image data and 9.6 kbps for the return in simplex mode, although full duplex 64 kbps service has been announced. To accomodate the operation of MDIS hardware in undeveloped locations, a Teleradiology spoke can be installed into a standard Deployable Medical Systems (DEPMEDS) International Standards Organization (ISO) Shelter, shipped via military transportation to a remote area, and operated using generator power. This approach lends itself to contingency deployments and disaster relief operations.

4.3.7. Communications between radiologist and health care provider.

In Teleradiology operations, the problem of communications between radiologist and health care provider is especially acute because of their physical separation. MDIS Teleradiology accomodates a "management by exception" approach that is similar to the system found in a large hospital. Routine requests are provided to the radiologist for diagnosis in batch. Rooutine reports return to the spoke in batch. "STAT" requests, where the patient's condition is potentially life-threatening, are transmitted immediately after acquisition and interpreted by the radiologist immediately upon receipt. The radiologist reports findings directly to the health care provider by telephone. Likewise, findings of unexpected pathology on routine exams are reported telephonically. A third category of requests exists where a provider can request an expedited report that would contribute substantially to patient convenience. The radiologist can manually enter and "push" preliminary impresssions electronically to the spoke to accomodate "Wet Reading". "Wet Read" requests are followed by definitive diagnosis in the transcribed report. The radiologist's voice could be digitized and attached to the image for Wet Reads. The MDIS request for interpretation can also be annotated to request consultation between clinician and radiologist or between radiologist and subspecialist. The report approval and release process accomodates both overreading and staff approval of a resident's findings.

4.3.8. Hub responsibilities.

If Teleradiology is truly to be the practice of Radiology at a distance, Teleradiology operations must take a broader view of remote Radiology. Telecommunications cannot replace the presence of a radiologist onsite for special procedures. The diagnostic partnership between hub and spokes evokes a new concept in health care: Teleradiology spokes constitute a "virtual Radiology department" for the hub. The new concept implies more responsibility at the hub for spoke Radiology operations. This principle might be embodied in a new clinical position at the hub, such as "Chief of Remote Diagnosis". This hub clinician would be responsible for deciding whether fluoro exams would be performed at the spoke by a contract radiologist or a "circuit rider" from the hub, whether ultrasound exams could be performed by a qualified technologist or whether a radiologist's presence is demanded. The Chief of Remote Diagnosis would make similar decisions about mammography and CT at the spoke. While small hospitals may have access to mobile CT services, CT without a radiologist is risky because of the possibility of contrast reactions, the need for requests to be screened to assure that they are indicated, and the need to specify protocols and slices. The Chief of Remote Diagnosis could also provide oversight of spoke Radiology operations including protocol review, quality assurance, technologist training, and could become the Champion for spoke Radiology departments in obtaining resources, personnel, imaging devices, and training.

5. CONCLUSIONS

The Defense Medical Establishment has commiuted to extensive implementation of sophistocated Teleradiology systems over the next three years. Success of MDIS Teleradiology depends on the quality of design and installation as well as operational aspects. The system must be designed to be modular enough to match a variety of clinical scenarios. The system must be flexible enough to accomodate changes in clinical practice and technology. The system must be configured based on an accurate definition of the clinical scenario, and requires that hospital managers be willing to adapt operations to make the most effective use of the new technology.

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Early Evaluation of MDIS Workstations at Madigan Army Medical Center

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ABSTRACT

The image viewing workstation is an all-important link in the PACS (Picture Archiving and Communications System) chain since it represents the interface between the system and the user. For PACS to function, the working environment and transfer of information to the user must be the same or better than the traditional film-based system. The important characteristics of a workstation from a clinical standpoint are acceptable image quality, rapid response time, a friendly user interface, and a well-integrated, highly-reliable, fault-tolerant system which provides the user ample functions to complete his tasks successfully.

Since early 1992, the MDIS (Medical Diagnostic Imaging Support) system's diagnostic and clinical workstations have been installed at Madigan Army Medical Center. Various functionalities and performance characteristics of the MDIS workstations such as image display, response time, database, and ergonomics will be presented. User comments and early experience with the workstations as well as new functionality recommended for the future will be discussed.

1. INTRODUCTION

The Medical Diagnostic Imaging Support (MDIS) System is a large PACS and teleradiology project for the U.S. military . The contract was awarded to a joint venture between Loral and Siemens in late 1991. Presently, Madigan Army Medical Center, Brooke Army Medical Center, and Wright-Patterson Air Force Medical Center are undergoing phased implementation of this system. Several other sites are planned for 1993-94, including military medical treatment facilities in the continental U.S., Hawaii, Korea, Panama, and the Azores off the coast of Portugal.

The shortcomings of a traditional film-based system are apparent. Films are frequently lost or unavailable when the clinician needs to see them. In a recent survey at one of our medical centers, 69% of clinicians stated that film accessibility was the greatest problem within radiology. The clinicians reported that the average time to find each study was 20

minutes and they spent atotal of 30 minutes to 1 hour per day locating films [1]. In an objective study of film accessibility at the same institution, 16.5% of inpatient radiographs imaged within the preceding 8 to 48 hours could not be located, and 38% of non-chest x-ray inpatient studies could not be located [2]. When radiological studies cannot be found physician efficiency and the quality of patient care are adversely affected. The maintenance of film libraries and film handling is labor-intensive and requires large storage areas . An average 350-bed hospital may spend $700,000 / year on film and chemicals [3]. Yet, with all of its shortcomings, the traditional film-based system has been the best option available .

Recent advances in PACS now offer solutions to these problems. A digital image can be viewed in multiple locations simultaneously, image accountability is greatly enhanced, clinician efficiency and patient care are improved, and expert consultation from distant sites is possible. The use of computer-aided diagnosis for screening images for pathology is theoretically possible and will become available in the future. The concept of PACS has been discussed for more than ten years [4]. The problems have been image quality, display speed, reliability, and user friendliness. For a system to be successful, it must be accepted by the end users - the clinicians and the radiologists. The end users interact with a PACS system at the workstation. Therefore, for a PACS system to succeed, the workstation must be user friendly, fast, reliable and display acceptable quality images.

The new Madigan Army Medical Center opened its doors in the Spring of 1992. Madigan is a 1.2 million square foot, 416-bed facility in Tacoma, Washington. Approximately 500 physicians representing nearly all subspecialties work at this tertiary care medical center and see over one million outpatient visits per year. The Department of Radiology with 12 staff and 18 residents, performs over 160,000 radiological exams per year.

2. SYSTEM OVERVIEW

2.1 Technical

The initial phase of MDIS at Madigan includes computed radiography for all plain x-rays except mammography and scoliosis series, a 20 Gbyte Working Storage Unit (WSU), a 100 platter (1 Tbyte) Optical Disk Jukebox (ODJ), and nine workstations. The computed radiography images are processed by two Siemens Digiscan 7000 and three Fuji AC1 plus readers. Third generation Fuji imaging plates are used. The Working Storage Unit (WSU) uses a redundant array of inexpensive disks (RAID, level 2 architecture). It functions as the local and short-term storage using 40 disks (magnetic media) operating in parallel; 32 disks for a 32 bit word, 7 disks for error correction , and one disk acting as a "hot spare" (single disk failure detected and corrected without loss of operation). The WSU is designed to hold inpatients for the average length of a hospital stay (4.5 days for Madigan), all outpatients for 48 hours, all exams not yet interpreted, and pertinent historical images. Images will be stored in the WSU with approximately 2.5:1 lossless compression (currently no compression is used on the WSU). Image retrieval bandwidth is greater than 400 CR image equivalents per minute. The full implementation WSU will have five times the present storage capacity (by doubling the capacity and implementing 2.5:1 compression). The WSU is connected to the workstations by a fiber optic network in a modified star topology. Image data moves with FDDI- like speeds (100 Mbits/sec). Images are transferred at the earliest opportunity from the WSU to the ODJ. The ODJ holds 100 (10 Gbyte)WORM 14" optical disks. Computed radiography images are stored with 10:1 lossy compression (modified JPEG format). The final phase calls for two ODJs which will be able to store about 3 years of images on line [5]. Presently, as part of the phased implementation, all computed radiography (CR) and fluoroscopy images are stored both softcopy and hardcopy (laser printed film) with the exception of GI barium cases which are softcopy only. CT and MRI images are expected to be available on the PACS in April of 1993. Nuclear medicine, ultrasound, angiography, and radiation therapy will be connected to the system in late 1993. A total of 9 workstations are presently in service: one each in the orthopedics clinic, the emergency room (ER), and the intensive care unit (ICU), with the rest in the radiology department. In the Summer/Fall of 1993, 116 additional workstations will be

placed throughout the clinics and wards of the hospital. Following this installation, Madigan will begin to go almost entirely filmless.

3. WORKSTATION OVERVIEW

3.1 General

Various types of workstations are being used based on the clinical need and cost constraints. MDIS supports two basic types of workstations, a standardized and an optimized. The standardized workstation is a high volume, primary diagnostic unit whereas the optimized workstation is a lower volume unit for clinical review of images. The standardized units can have either 2K (A type) or 1K (B type) resolution portrait monitors. The optimized units have only 1K (C type) resolution landscape monitors. The primary diagnosis for CR should be made on the 2K monitors. Lower resolution modalities such as ultrasound can be read on any of the monitors. In the radiology's primary reading areas standardized workstations with four 2K monitors are used. In general, the wards and clinics will have two 1K monitors at optimized workstations, but the entire 2K data set is available by magnifying the image either by a zoom function or use of the "magic glass" tool in the region of interest. All the workstations have the same basic image manipulation functions. One drawback to the 2k monitors is that presently the Macintosh headings are very small, making them difficult to read. This problem is being addressed by the vendor. The primary advantage of the four monitor workstations over the two monitor workstations is convenience and speed. Comparing multiple images can be done with two monitors, but significantly more image manipulation is necessary. Initially, we considered eight monitor workstations (4 on top , 4 on the bottom simulating a conventional alternator board); with our present experience we do not feel that the added benefit would justify the costs. Even large barium series can be comfortably reviewed on the four monitor workstations.

3.2 Technical

The basic platform for the workstation is the Macintosh IIfx computer with 8 MB RAM and 80 MB internal disc drive. Loral and Siemens then insert special image processing boards . The primary difference between the standardized and optimized workstations is the OPUS boards with 64 MB and 32 MB of image memory respectively. A key feature of the system is the connection between the workstation, database, and WSU. The workstation queries the database via an Ethernet line. The database provides the workstation with the necessary information and access rights to retrieve image data from the WSU. The WSU transmits images to the workstation via a direct fiber optic link to the image memory of the OPUS board, with as many images as possible stored on the OPUS board. Once full, the system automatically pages images in from the WSU.

Although meeting the MDIS specifications of at least 40 ft. lamberts, the A monitors seemed too dim. The transmittance filters were changed from 30% to 60% so that now the A monitors give off 80 ft.-lamberts of luminance. Changing the filter further increases the risk of glare off the monitor screen. The brightness of the monitors has been a concern, especially in the emergency room where the overhead lighting cannot be controlled. In our opinion, brighter monitors would be helpful. Technical specifications of the monitors are summerized in tables 1 and 2.

3.3 User friendliness

The Macintosh-based interface is one of the keys to the user acceptance of the system. It is quite user friendly. This is critical because many of our clinicians are computer illiterate. Ease of training is directly related to the ease of use. We have also noted that the retention of knowledge on how the workstation functions is high. Both ease of initial training and retention of training are believed to be due to the mouse-driven pull-down menus. As in the normal Macintosh format, "quick keys" are available for the commonly used functions so that an experienced user can move through the functions more rapidly.

4. WORKSTATION FUNCTIONALITY

4.1 Work lists and displaying images

Several work lists are available, the most commonly used one is the "all exams" list. Work lists are site configurable and can be added at any time. The user can click on the patient's name or if the list is long, type in the patient's name to bring it up to the front. Once the study is selected, the patient's requested information, clinical history, and dictated report (if completed) are automatically displayed. The user can search for a study by any one of the headings or combine headings to limit the list. Double clicking on a patient automatically brings up a list of all of that patient's other imaging studies. Once the desired imaging study is located, the clinician can click on "Image" and drag the mouse down to "Display image" or just use the quick key "Apple D" to view the image.

4.2 Imaging modes

There are two primary ways to view the images, the traditional or "diagnostic " mode in which images are side-by-side, and the "cine" mode in which all the images in the series are stacked one behind the other. The latter mode is especially helpful in axial CT or MR series when following a structure in the cranial to caudal direction. It is also useful for looking at multiple images of the same anatomic region over a short period of time such as a barium swallow. Within the cine mode, the images can be viewed as a movie or image by image based on the user's desires.

In the diagnostic mode, multiple formats are available, one image per screen, two images per screen, up to 90 images per screen. The size of individual images can be changed. Single images, groups of images, or all images can be manipulated at once. If more images are present than are seen on the screen, a "Page down" phrase is highlighted. For QC purposes, individual images can be hidden to the user. An icon to alert the user of hidden images is being implemented. A special key ,"Apple Z," is present to undo the last action whenever necessary . In addition, if a hardcopy of any study is needed, the user can click on "print to film" and pick up the film from the network laser film printer.

4.3 Imaging tool palate

The following image manipulation tools are available on the system: window/level, magnify, pan, region of interest signal measurement, distance and area measurement, annotate, flip/rotate, equalization function, the"magic glass," and inverted gray scale. The window/ level can be changed simultaneously with the mouse or the user can set his own preselected window/level values. A special function called the magic glass is extremely useful. This gives the user a window box in which either magnification of the image by a factor of two, inversion of the gray scale, or equalization of the image within the box can be done without changing the rest of the image. The user can rapidly scan the study by moving the box around the image. By depressing the Apple key at the same time, he can also change the window/level within the box. By depressing the option key,he can continue to magnify the image. Depressing the control key changes the size of the box. The image manipulation within the box occurs instantaneously, and we have found this function to be very useful.

The invert gray scale is helpful in locating the tips of tubes and lines. It also appears to increase the conspicuity of polyps in barium GI studies, and certain bony structures such as sub-diaphragmatic ribs on a chest x-ray. The workstation allows the user to hide patient images (for QC of images not acceptable to be presented to the radiologists and clinicians), demographics (useful for patient confidentiality issues) and/or annotations.

The initial software format for comparison of old images was awkward. The vendors were made aware of this and a new software release is planned for Spring of 1993 which will make comparison to old images easier and more natural.

5. RIS INTERFACE

The radiology information system (RIS) is an integral part of the MDIS workstation. Once the user selects a patient's study within a work list, the radiological request and dictated report (if completed) automatically show up on the bottom of the screen. Therefore, the patient's clinical history, radiological images, and dictated report are present together on the workstation monitor for the radiologist or clinician to see. An internal review performed at Madigan before installing the MDIS system showed that of randomly selected radiological cases, the patient's dictated report, images,or both could not be found in the fileroom in 50% of the cases. The MDIS system is expected to virtually eliminate this problem. The Composite Health Care System (CHCS), the Department of Defense's hospital information system (HIS), is expected in the near future. The MDIS system will be (by contract) compatible with CHCS.

Usually the radiologist dictates a report to a transcriptionist, but if he desires, he can type in the report himself. Standardized radiology reports are available on pull-down menus. These standardized reports are used almost exclusively on the Gastro-Intestinal (GI) service, frequently with slight modifications, such that final reports are now often available to the clinician the same day as the study was done. Using the RIS, the database manager can generate a report giving the department a more exact account of workload statistics, thereby helping to locate problem areas, support QA/QC evaluations, and document man-hour requirements. The RIS is also very valuable as a research tool. Database queries can be formulated in many ways. Each report has a space to log in an ACR radiological/pathologic code and a specialty code (code designed by users) for teaching and research purposes. Madigan radiology residents are already in the habit of digitizing interesting outside images into MDIS as teaching file cases and saving them under a specific specialty code.

6. SECURITY

Each workstation user is given his own unique secret access code. The database manager is the only individual who has access to this number. Users are assigned specific privileges based on their job functions. For example, only selected users are able to print a hardcopy x-ray film from the MDIS system. For security purposes, the system is designed to log the user off if the user does not have any active interaction with the keyboard for 10 minutes. In reality, this feature was found to be quite irritating and has been a source of many complaints. Frequently a radiologist or clinician gets interrupted in the middle of viewing the images and the system turns itself off before the user has finished looking at the images. We are in the process of expanding the time-out period to 90 minutes which should alleviate the problem. The purpose of this feature was to satisfy a security requirement of the contract. This is being relaxed on a per device basis if the workstation is considered to be in a secure area.

7. ERGONOMICS

Scattered light is a concern of the radiologist because it decreases the relative contrast of the images being viewed. The average luminance of a film on a viewbox is 200 foot lamberts .Our A and B monitors emit 80 and 60 ft-lamberts, respectively. Therefore, the light level of the room is of even greater significance. Our radiology viewing areas which house the workstations have dimmer switches to finely control the lighting. Some workstations are located in areas where the lights cannot be dimmed such as in the ER. In these areas, brighter

monitors would be especially helpful.

The chairs for the workstation are specially designed for maximum viewing comfort. The workstations have adequate table space for a phone, dictation system, keyboard, mouse, and the necessary paperwork.

8. TRAINING

We plan to train all clinicians, nursing staff, and key ward and administrative personnel. The radiologists, radiology receptionists and typists, and most orthopedic, ER, and ICU physicians have already been trained. In all, over 770 personnel will be trained initially on the workstation. In the military and especially at a military training hospital, the turnover rate of personnel is high - an estimated 25% turnover rate per year is the norm. Therefore, follow-up training is as important. Ease of training is directly related to the ease of use. We have also noted that the retention of knowledge on how the workstation functions is high.

So far, only a limited number of clinicians have received formal training, yet a survey of 75 internists, general surgeons, intensivists, and pediatricians at Madigan shows that 77% know how to use the basic functions of the workstation (only 7% polled had formal training). Nearly all of the interns can use the system. Several have received informal training from the site program manager who has been training personnel on an individual basis since the workstations first arrived. The remainder are learning from their peers. Daily, clinicians can be seen teaching the system to other clinicians, and some have learned the system entirely on their own without any training. The remarkable number of people that have learned the system without formal training reinforçes two hypotheses. First, the system is easy to learn. Second, clinicians are taking time out of their busy schedule to learn how to use the workstation because it is a better way of conducting business. They have found it is faster, more efficient use of their time, and more reliable to review a patient's images on the workstation than to go and look for the film in the fileroom.

The workstation training will be geared to the user. Some users need to understand all functions whereas others can initially learn only the basic functions. The vendor provides professional trainers familiar with the hospital environment. All personnel have the option to take a Mac-basics course before the workstation training if they wish. The workstation training includes a short classroom portion and an in-depth hands-on session. Complete manuals are available during and after the class, but a more useful item is a laminated "carry in your pocket" quick reference card. Follow-up training of new personnel will be done by on-site Loral personnel working with the system. An on-site hotline is planned to assist users who have questions, complaints, or new ideas regarding the workstation. The user can dial a phone number or pager number. Short "quick help" videos on common problems encountered by the user will be available on-line (stored in the WSU) at each workstation. Initial training will be mandatory for all users but those that were self-taught or received training from a peer will be able to test out of the training program.

We strongly believe a formal training program is necessary to the success of the system. For example, although a high percentage of clinicians can pull up a patient's images on the monitor, only 21% stated they were comfortable with all of the functions available to them. Several requested more formal training and aids as described above. The MDIS project office together with the vendors have been developing a series of concise user-specific training modules to be implemented soon.

9. QUALITY CONTROL

The Quality Control (QC) chief checks the images on a workstation monitor as they are generated for problems, e.g., mis-centering , artifacts. At the same time, he makes sure the images are presented on the monitor in the way the radiologist expects them, which saves the radiologist valuable time manipulating images during primary diagnosis. We have found this to be very useful to the radiologists and clinicians.

With making the primary diagnosis directly on the workstation, comes a whole new set of mandatory quality control measures to ensure adequate patient care. All the MDIS components along the pipeline of bringing images from imaging modalities to the user (e.g., CR, network connection, workstation monitor, and laser film digitizer) must be periodically checked and tested individually and collectively. The brightness of the monitors drifts gradually over time, and the luminance and spot size can vary significantly across the screen. The fiber-optic distribution (FOD) can fail; pixels with signal dropout simulate the dense white appearance of metal fragments in a traditional film/screen image or the artifact of dense white flecks caused by a dirty screen. Loral views this as a design deficiency and is correcting the problem. The FODs at Madigan have been upgraded with more forgiving timing to prevent this type of "signal dropout". The newer fiber optic interfaces (FOIs) will incorporate a checksum mechanism to ensure that errors can at least be detected and that corrupted data will not be stored on the WSU.

In a traditional film-based environment, when a technologist underexposed a patient's film, it turned out white with almost no image; overexposure led to a black film. With computed radiography (CR), both the under and overexposed patient imaging plates lead to a visible image. The radiology technologist soon realizes the only risk he takes is if a patient's imaging plate is still significantly underexposed, the image looks noisy (due to quantum mottle). Therefore, there is a tendency to overexpose the patient's image plate to reduce any risk of having to repeat the study. The best way to follow the patient exposure with CR is the Sensitivity (S) number (a rough inverse correlation with x-ray dose). This number is displayed when a hardcopy laser image is printed. In a filmless environment, this number must appear somewhere with the image on the workstation monitor. Otherwise, there is a risk of routinely overexposing patients.

10. DETERMINING LOCATION AND NUMBER OF WORKSTATIONS

It is important to clearly establish the number and location of the workstations to be placed throughout the hospital in the early stages of the project. Clinical workstations are planned for all of the "team center " workrooms on the various wards. The Madigan MDIS site manager and the MDIS system manager met with each department within the hospital to discuss their clinicians' preference in terms of locations of the workstations. The clinicians within each department were asked what was the maximum number of physicians working in their clinic at any given time and the percentage of time they spent looking at radiographic images. Based on the data given by the clinicians, the number of workstations needed in each clinic was determined. In some situations, additional workstations were added due to logistical problems with the departmental layout. By working directly with the individual departments and having them provide the data for estimating the number of workstations, the departments and clinicians develop some responsibility and accountability for the number and location of workstations in their sections.

11. WORKSTATION TESTING

11.1 Image accountability

The failure of a conventional film-based system on image accountability is one of the primary reasons to convert to a PACS environment. It has been stated that PACS will result in zero image loss. In reality, this has not been realized yet. Some images are still misplaced, but this time electronically. During summer of 1992, we reviewed 150 studies done in the first 3 months at Madigan after moving into the new hospital. Hardcopy laser printed images could not be found in 20% of the cases. Surprisingly, 10% of the cases could not be found on the MDIS system. Closer examination showed that some studies were located under a different folder heading, e.g., a chest x-ray listed as an abdomen; other cases coming through the emergency

room were initially listed as "John Doe" and never converted to the proper name in the database. Finally, in the first 3 months of operation, there were a significant number of "bugs" to work out of the system. Action has been taken to address these problems. A follow-up study was done in which a week (early November of 1992) was randomly selected to review image accountability. The image in question could be found in its exact heading or similar title (e.g., toe under foot heading) in greater than 98% of cases. In some cases, the patient's name was incorrect, in others the image was under the wrong heading as was the case with initial operation of the MDIS system at Madigan. This was most common when multiple studies were done on the same patient especially in an emergency situation- the radiology technologist only made up a single barcode and put all the images under this heading. We are presently educating our technologists on the importance of using a barcode for each study and working with the vendors to design a tool to transfer images to the proper heading.

11.2 System reliability

A high level of reliability is critical to the success of a PACS. Our contract calls for 98% system up time. Any down time of the VAX, WSU or ODJ can affect the user at the workstation. Over the initial 10 months, the MDIS system has been up and running 98.8% of the time. Presently, one of the major causes of down time is related to the air conditioning system. We have an Uninterrupted Power Supply (UPS) but no back-up air conditioning system in the computer room exists presently. The equipment in the computer room generates a significant amount of heat. The central hospital air conditioner has failed several times, in each case the MDIS system has to be brought down due to the danger of overheating. We are presently working on acquiring a back-up air cooling source to resolve the issue. Excluding air conditioning related problems, the system has been operational 99.7% of the time. During the down times, the system is in the "fail over"mode. Hardcopy laser printed images are produced which can later be digitized back into the system. During this mode two copies of each image are obtained. One is released for diagnosis and clinical use and the other image is retained by the technologist to digitize at a later time. Otherwise, the process to find the images to digitize later is highly labor intensive and the same problem occurs as in an analog system, namely some of the images are never recovered again. We feel the extra cost for two images is justified, especially since this is a very infrequent problem.

11.3 Image display speed

Image display speed on the workstation is primarily related to the location of the image data at the time of the request. In general, if the image is still on the WSU, it takes 5-6 seconds to display the image on the monitor. This time is fairly consistent. The vendors are working to reduce the time to less than 2 seconds. If the image is archived on the ODJ, the time to display is much longer and presently averages 1.8 minutes . The time to display an image from the ODJ is variable with several factors influencing this display speed. Only one study can be fetched at a time, therefore the time depends on the number of studies that other users are seeking at that time. Presently, if the ODJ is in the middle of archiving another case, it must complete the task before retrieving the study requested. A software change is expected shortly that will interrupt archiving to service fetch requests. A special "fetching" worklist is being developed by the vendors that will allow users to easily check on the status of an exam they are fetching while allowing them to proceed with other cases on the workstation. We believe this will increase the tolerance of the user for the fetching time delay. However, fetching from the ODJ is one of our greatest concerns. Presently,there are only nine workstations in Madigan,but this summer the number will increase to 125. As more users have access to the system, more fetch requests are expected. Several solutions are planned. Prefetch algorithms exist in the software such that studies on the ODJ expected to be seen the following day can be fetched the night before during low-use periods and stored on the WSU. However, this function is presently disabled to ensure sufficient storage exists on the WSU for new exams. In the final configuration, the WSU will have five times the present storage and will allow the prefetch

algorithms to be implemented. Once the HIS is implemented in the hospital, prefetch algorithms can be linked to scheduled outpatient clinic visits. Bottlenecks are not expected to be significant at the WSU based on simulation studies done by the vendors [6].

The time to paint images on the screen depends on the data set, screens and type of workstation. The following is a general example of the screen paint speed. Given a 50 image CT study on a standardized four 2K monitor workstation in the 12 images on 1 page format (12:1), it takes on average 57 seconds to paint the entire study. In practice, this number is less important because the clinician can start his evaluation of the study once the first screen is painted (about 5-6 seconds). To convert this study to the stacked cine mode takes 7.9 seconds, and returning to the 12:1 format takes 15 seconds. To page down to the next set of images (display images of the study that did not fit on the first four screens) takes 2.5 seconds. Paging up takes 1.8 seconds. These times are expected to improve on the diagnostic workstations with improved imaging boards the vendor is planning to deliver.

11.4 Hardcopy vs. softcopy reading times

As opposed to a clinician that may review a few imaging studies a day, the radiologist spends the majority of his day looking at images and making diagnoses. Even a small percentage change in the rate at which he reviews images, can therefore have a major effect on his overall work efficiency. We tested the time it took three board certified radiologists to review and dictate the same 30 CR imaging studies. Each reader reviewed the 30 cases both softcopy on a standardized four 2K monitor workstation and hardcopy as laser printed images. The soft and hardcopy sessions were separated by at least 3 weeks in 2 of 3 cases. The 30 cases were randomly selected outpatient imaging studies composed of 10 bone, 10 supine and upright abdomen, and 10 single-view chest x-rays. The order of reading (softcopy images first vs. hard copy images first) was varied.No old comparison images were used. The hardcopy images were separated out and placed on top of the master jacket. Timing measurements began with the radiologist reaching for the images placed beside him and ended after a handwritten report was generated and the study placed into the master jacket. The softcopy cases were stored on the WSU in a random order such that the radiologist had to type in the patient's last name to retrieve the images. The images had been properly oriented and brightness and contrast adjusted in a quality control step prior to viewing to minimize the need for additional manipulation. This QC step is a routine part of our daily operation.

There was no significant difference in the readers in regards to pathology reported. Although this was not intended to be and is not a study of visualization of pathology and diagnostic efficacy, the readers noted all findings in softcopy that were seen on the hardcopy images. Angle measurements made on the workstation seem to be more consistent than the measurements made on the hardcopy images with the goniometer.

Overall, reading images on the hardcopy was 35% faster than the softcopy images. Yet this varied significantly between the experience of the reader and even the type of study being read. The experienced reader was only 9% faster hardcopy than softcopy. The two less experienced readers actually began reading softcopy images faster as the test progressed - the first reader went from reading hardcopy 50% faster to only 36% faster; the second reader went from 45% to 24% faster on the hardcopy. This probably reflects the learning curve involved in reading softcopy. Several software features have not yet been implemented on the MDIS workstations that are expected to significantly speed up the softcopy reading times. The work lists are being improved so that a radiologist will be able to go through a specific list of studies assigned to him. A "next patient " quick key is planned. This will allow the radiologist to proceed to the next patient's images without typing in a name. In this study we did not use old comparison images. At this time, the format on the MDIS workstation to compare old images to the present study is awkward; a new format for comparison images is expected soon. Also, prefetch algorithms to automatically bring the old studies from the ODJ to the WSU will be implemented once the WSU capacity is increased. We believe these features will make softcopy reading competitive with the traditional film environment.

With conventional film, the image cannot be manipulated, whereas on the workstation with several easily accessible imaging tools at the radiologist's disposal, an attempt can be made to extract additional information that was previously unavailable. The user now balances time with depth of investigation of the image. It is possible that in the future, each specific study type will have two or three preset window/level settings (like in x-ray CT) or levels of enhancement. These presets would be on single stroke quick keys. Eventually, the more that the intermediate steps in patient selection, image display and manipulation can be avoided and the better streamlined the overall process is made for the radiologist, the faster the reading of the images will be.

11.5 Image quality

At a minimum, 1K monitors with the ability to magnify the image and retrieve the whole 2K data set are necessary to view CR images. The 2K monitors are preferred for the primary diagnosis. Presently all CR images are available both on hardcopy and softcopy. After more than 10 months of clinical use and 100,000 CR studies, to our knowledge, no cases have been documented in which a finding was noted on the hardcopy, but not on the softcopy image. On the other hand, several clinical findings are routinely noted on the workstation that are inconspicuous or absent on the hardcopy images. Another advantage of softcopy with CR images is that the Fuji contrast imaging algorithms (G factors) have no effect. In some cases, we had problems with the original Fuji algorithms (e.g. feet, barium studies) giving suboptimal hardcopy images, while on the monitor they look fine. At this time, edge enhancement and unsharp masking are not available at the workstation. This is planned to be incorporated in a future release.

Simple pixel replication is used on the system instead of interpolated zoom. This causes the CT and MR images to look pixelly when viewed on the workstation in the traditional 12:1 format. This is unacceptable to the radiologists and is being worked on by the vendors.

Primary diagnosis is only made on images with lossless compression. We are using 10:1 lossy compression on CR images after a primary diagnosis has been made and before archiving the images in the ODJ. The decision to use lossy compression on archived images may be considered controversial by some, but several studies in the literature support this approach [7-10]. We believe that with 10:1 compression, clinically relevant information is not lost; a large ROC study will soon begin at Madigan to test this hypothesis.

12. PROBLEM AREAS

Several of the areas of concern have been mentioned earlier including the "John Doe" issue, the need for more specific work lists, the small print headings on the 2K monitors, the brightness of the monitors, and a better format to compare old image studies. An escape button is needed in unusual cases where a mistake is made and the database ties up the user while looking for an impossible entry. The users should be informed when the system will be down or is malfunctioning. A message on the workstation would be helpful. Graphical overlays such as the slice position on the CTs and reconstructed CT images are not coming over to MDIS. The vendors are working on these issues. We do not have color monitors for nuclear medicine thallium studies or ultrasound color Doppler flow cases. Our present strategy is to use a mini PACS concept for ultrasound and nuclear medicine, keeping color images in these areas and not sending color to the 125 workstations around the hospital. The number of clinicians needing to see color images is limited and modifying all of the workstations would be expensive.

Image navigation is the area needing the most improvement. Studies should have preselected defaults with images coming up on the workstation in a specific arrangement. For example, in MR it would be useful to see the same anatomic axial slice side by side in T1, proton density and T2 sequences. Then in a stacked mode, one can move through the remaining axial slices similar to the technique in [11].

13. CLINICAL ACCEPTABILITY

A recent survey of 58 surgeons, internists, and pediatricians at Madigan revealed that 100% believe the MDIS system is useful to them, 100% believe it saves them time, and more than 98% believe it helps to improve patient care. As mentioned earlier, many clinicians have learned how to use the system before they received formal training. This is because they believe that the system saves them time and effort. With only the nine workstations currently installed, it is already better than the traditional film-based system. Clinicians now routinely go to the workstations in radiology to look for imaging studies instead of going to the fileroom. It is clear that the place where PACS is most appreciated is on the wards and clinics. The orthopedic department has a workstation in its clinic. In the past , patients that arrived for follow-up appointments for fractures without their old x-ray films would either be canceled and told to return with the films or to retake x-rays. In their busy clinic, the orthopedic surgeon could not afford the time to go down to radiology and try to find the old film. Now he can just pull the patient's old study up on the workstation in his clinic, thus saving time, money, and/or unnecessary additional radiation exposure to the patient.

In specialty areas such as the ICU, traditionally an area first targeted by PACS [12,13], the advantages are more subtle. The ICU chest x-ray hardcopy images are maintained on a large dedicated alternator board in radiology. The images are sent straight to the board, thus bypassing the fileroom. The ICU team comes to radiology each morning to review the morning chest x-rays. Therefore, some of the traditional problems of the film-based system are not a problem in this environment. The advantage comes in the middle of the night or day when a patient is in acute distress and time is critical. The clinician can view the patient's images in this case without leaving the intensive care unit. It is in this scenario that the workstation in the ICU demonstrates its usefulness.

The GI radiology service is completely filmless now. The radiology technologists on GI believe being filmless saves them time. We are planning timing trials to verify this claim. The radiology residents and staff also prefer the filmless environment in GI. The imaging tools, such as the magic glass, inverted gray scale and magnification, seem to be especially useful on the GI service. The general feeling of the radiologists at Madigan is that the system has great potential, but better image navigation software would enhance the value of PACS significantly. PACS is (and will remain so in the near future) most beneficial to the clinicians, not to the radiologists. Having workstations on the wards and clinics will be the pathway by which PACS will succeed and be widely accepted in the field of medicine.

14. FUTURE DEVELOPMENTS AT MADIGAN

In the following months, the remaining imaging modalities such as ultrasound, nuclear medicine, angiography, and radiation therapy will be integrated into the system. The remaining 116 workstations will be placed throughout the hospital. The Hospital Information System for the military (CHCS) is expected to be installed and MDIS will be interfaced with this system. Prefetch algorithms to bring images from the ODJ to the WSU and a larger storage capacity at the WSU will improve image retrieval times. Special clinical sub-folders are being designed to allow key images from different sub-folders to be located together, e.g., a patient with a lung mass might have a folder with his previous two chest x-rays, a chest CT, and a bone scan in it. This would allow the clinicians more rapid access to the studies they are interested in and also decrease the overall amount of image data passing through the network since the selected images are fetched instead of all of the patient's images. A gateway is being developed to provide for teleradiology connections to other hospitals and clinics within Madigan's referral region.

Special equipment is expected to allow the downloading of image data for later manipulation and research purposes. A 35 mm slide maker attached to the workstation will facilitate teaching and publications. Previously, all authorized users were allowed to print out a hardcopy image of any case from the workstation. Clinicians have developed a habit of

printing out many cases on hardcopy instead of going to the fileroom which takes more time. This privilege was temporarily suspended to all physicians except radiologists due to film cost. Eventually when users print a study to hardcopy, the system will either debit or charge this to the user and his department. Then the privilege to print any study will again be allowed, but the individual or department can possibly be billed for the cost of the laser print film. If the program progresses as planned, we hope to go predominantly filmless in the fall of 1993.

Once at the workstation, the user could potentially have rapid access to massive amounts of information such as on-line anatomy textbooks, atlases of normal radiographic variants, gamuts of radiological differential diagnoses, and medical literature search capability. This is a desired future development.

The greatest area of future software development needs to be in the area of image navigation - the way the image data sets are presented to the radiologist and the way he is able to manipulate the images within the study set.

PACS is closing the door on one of the oldest and most problematic areas of radiology-image accountability. We need now to investigate the other major limb of radiological service, the speed and access of the dictated report of the image to the clinician and his patient. The MDIS system ties the report to the image ,making it accessible, but too often there is a major delay in the time it takes the report to get onto the system. Although speech recognition dictation is not part of the present MDIS contract, we are investigating this issue .

15. CONCLUSIONS

The early Madigan experience demonstrates that the MDIS workstation is very user friendly and enjoys an enthusiastic, wide acceptance from the clinicians. The image quality is high and the overall reliability of the system is remarkable. A PACS workstation is most helpful to the physicians on the wards and in the clinics. The Madigan experience demonstrates that early PACS' claims to be useful, to save clinicians time and to improve patient care are being realized. The most important area for development in the immediate future is new software for better image navigation. This is critical in order to speed up the radiologist's ability to review large numbers of imaging studies on the workstation. A long-term goal is to integrate a functional speech recognition dictation program into the MDIS system to improve the delivery of the radiologist's dictated report to the clinician and his patients.

The MDIS program, with support from academic institutions like Georgetown and the University of Washington, works with vendors that are willing to adjust and change as new ideas and problems arise. Computer specialists, engineers, physicists, and the end users (the physicians) have all been involved in the software development and evolution. A users group made up of the vendors, individuals from the various MDIS locations, and our sister programs at the Hammersmith Hospital in London, England and the Veterans Administration Hospital in Baltimore meet several times a year to share new ideas and discuss problems. The group communicates through an active electronic mail system. User groups are also now present at the individual sites helping to facilitate the end user's input into the decision making process. All of this interaction has helped to make the MDIS workstation more clinically useful and acceptable, and we are working together to improve various functionalities based on our early experience to make the MDIS workstation a success.

16. ACKNOWLEDGMENTS

We would like to thank Mr. Robert Glicksman, Senior Scientist at Loral Western Development Labs for his technical consultative support.

TABLE 1

PARAMETER	RFP SPEC	A TYPE MON.	B TYPE MON.
SPATIAL RESOLUTION	A-1536X2048 B-1024X1280	1536X2048	1024 X 1280
VIEWABLE RASTER DIAGONAL	17 TO 23 in	19 in (14.0X10.5 in)	21 in
BRIGHTNESS	A>40 ft-L B>60 ft-L	>60 ft-L	65 ft-L
REFRESH RATE	FLICKER FREE	70.5 Hz. NON-INTERLACED	72 Hz. NON-INTERLACED
MONITOR CALIBRATION	MATCH MONITORS TO WITHIN 5% OF BRIGHTNESS AND CONTRAST	MATCH MONITORS TO WITHIN 5% OF BRIGHTNESS AND CONTRAST	MATCH MONITORS TO WITHIN 5% OF BRIGHTNESS AND CONTRAST
BRIGHTNESS UNIFORMITY	<15%	<15%	<10% OF SCREEN CENTER
LINEAR DISTORTION	<3%	<3% @ 35 degrees	V<2% H<3%
SPOT VARIATION	<50%	<25%	<30%
VIEWABLE GRAY SCALE DISPLAY	8 BITS	8 BITS	8 BITS
AUX. OUTPUT FOR SLAVE MONITORS	YES	YES - VIA EXTERNAL CONNECTION	YES - VIA EXTERNAL CONNECTION
BRIGHTNESS/ CONTRAST DRIFT	<5% OVER 3 MONTHS	<5% OVER 3 MONTHS (AVE. SCENE BRIGHTNESS < 35 FTL)	<5% OVER 3 MONTHS (AVE. SCENE BRIGHTNESS < 35 FTL)

TABLE 2

PARAMETER	RFP SPEC	C TYPE MON.
SPATIAL RESOLUTION	C= 880 X 1152	880 X 1152
VIEWABLE RASTER DIAGONAL	17 TO 23 in	21 in
BRIGHTNESS	A>40 fL B>60 fL	65 fL
REFRESH RATE	FLICKER FREE	72 Hz NON INTERLACED
MONITOR CALIBRATION	YES - MATCH MONITORS TO WITHIN 5% OF BRIGHTNESS & CONTRAST	YES - MATCH MONITORS TO WITHIN 5% OF BRIGHTNESS & CONTRAST
BRIGHTNESS UNIFORMITY	<15%	<10% OF SCREEN CENTER
LINEAR DISTORTION	<3%	V<2% H<3%
SPOT VARIATION	<50%	<30%
VIEWABLE GRAY SCALE DISPLAY	8 BITS	8 BITS
AUX. OUTPUT FOR SLAVE MONITORS	YES	YES
BRIGHTNESS/ CONTRAST DRIFT	< 5% OVER 3 MONTHS	< 5% OVER 3 MONTHS (AVE. SCENE BRIGHTNESS <35 fL)

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MDIS Quality Control Program Requirements

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Table of Contents

1. Introduction.
    1.1. Definition.
    1.2. Scope
2. General Requirements.
    2.1. Test & Measurement Equipment
        2.1.1. Radiation Exposure
        2.1.2. Radiation Quality
        2.1.3. Film Optical Density
        2.1.4. Monitor Luminance
        2.1.5. Test Image Generation
            2.1.5.1. Digital Test Pattern Files
            2.1.5.2. Radiographic Phantom
            2.1.5.3. Reference Hardcopy Film
            2.1.5.4. Video Test Pattern Generator
    2.2. Documentation
        2.2.1. Technical Data
        2.2.2. Evaluation Procedures
        2.2.3. Maintenance Actions and Modifications

Table of Contents (continued)

2.3. Program Management Database

2.3.1. General Description

2.3.2. Test Procedures and Results

2.3.3. Evaluation and Reports

3. Summary of Quality Control Requirements for MDIS Components

3.1. MDIS Image Acquisition Devices

3.1.1. Computed Radiography

3.1.2. Film Digitizer

3.2. Other Image Acquisition Devices

3.2.1. Digital Interfaces

3.2.2. Video Acquisition Interfaces

3.3. Image Output Devices

3.3.1. Soft Copy Image Display

3.3.2. Network Laser Printer

Appendix A. List of Technical Publications

Appendix B. References.

Medical Diagnostic Imaging Support

Quality Control Program Requirements

1. Introduction. This document provides the basis for implementation of a quality control program in the MDIS digital radiology department. Quality control is an integral part of the radiology department's quality assurance program. Radiological quality assurance addresses the optimization of performance of all aspects of the radiology department, including bothe equipment and personnel. Quality control deals specifically with the evaluation of the performance of equipment. A properly designed quality control program enables the radiology department to detect and correct deterioration of equipment performance before a loss of image information becomes clinically evident.

1.1 Definition. Quality Control is defined in NCRP Report No. 99 as a series of distinct technical procedures designed to detect deviation of equipment from optimal performance.[1] The technical procedures used for quality control must have sufficient sensitivity and be performed with sufficient frequency to detect slowly evolving changes before significant deterioration of image quality or equipment breakdown occurs.

1.2 Scope. The quality control program detailed in this document does not deal with x-ray, CT, ultrasound, nuclear medicine or MRI equipment. Quality control for these image acquisition devices which are interfaced to MDIS is necessary for the successful implementation of the MDIS Quality Control Program, and must be implemented in accordance with TB MED 521, AFR 161-38, and applicable manufacturer's recommendations. The MDIS Quality Control Program addresses all components provided as part of the MDIS contract, including the interfaces to existing imaging modalities.

2. General Requirements.

2.1. Test and Measurement Equipment.

2.1.1. Radiation Exposure. Proper analysis of computed radiography system performance requires the exposure of the imaging plates to a known and reproducible amount of radiation. A calibrated ionization chamber

[1] NCRP Report No. 99, Quality Assurance in Diagnostic Radiology, National Council on Radiation Protection and Measurement, Bethesda, MD (1988).

and electrometer is needed to measure this exposure. The instrument must be capable of measuring integrated radiation exposure (roentgens or coulombs/kilogram) at the exposure rates and energies commonly encountered in diagnostic radiology.

2.1.2. Radiation Quality. Analysis of the computed radiography system also requires knowledge of the quality of the x-ray beam used to expose the imaging plate. Radiation quality is specified by the energy (kilovolts peak) and filtration (millimeters of aluminum) of the beam. Kilovolts peak (kVp) is normally measured with a noninvasive kVp meter. Filtration is measured indirectly by determining the half-value layer of the beam. A set of Type 1100 aluminum alloy plates of known thicknesses (tenth millimeter increments) is required for this measurement.

2.1.3 Film Optical Density. The MDIS network laser imager and the direct-connect/docked laser imagers provided with the medium and high performance CR devices produce test films for which the optical density must be measured and recorded. A densitometer with an RS-232 interface can be connected directly to the network laser imager to avoid manual entry of calibration data. A densitometer is also required for verification of the optical densities of test objects used for quality control analysis of the MDIS film digitizers.

2.1.4. Monitor Luminance. Evaluation of monitor performance requires the routine measurement of monitor luminance. A calibrated luminance meter, which reads in units of foot-Lamberts (fL) or candela per meter squared (cd/m^2) is required for these measurements. The field of view of this meter should be narrow enough to measure the luminance from a 1 cm diameter circular region of interest at a distance of 24 inches. Luminance heads which have very short focal lengths and attach to the monitor with suction cups can be useful for eliminating variability in measurements which are caused by ambient room lighting conditions.

2.1.5 Test Image Generation.

2.1.5.1. Digital Test Patterns. In order to evaluate the performance of the soft copy image display workstations, monitors, and network laser printers, standard digital image test pattern files are required. The test pattern developed by the Society of Motion Picture and Television Engineers (SMPTE) for medical applications, is used for general quality control measurements.[2] Test patterns for other specific applications are also required. These test image files should be retained in the PACS archive with recoverable

[2]Society of Motion Picture and Television Engineers, "SMPTE recommended p;ractice, RP 133-1986, Specifications for Medical Diagnostic Imaging Test Pattern for Television Monitors and Hard-Copy Recording Cameras," SMPTE J. 693-696 (1986)

compression, and should be available for display on the workstations in their normal operating mode. A set of test patterns should be available in all imaging pixel matrices which are acquired and displaed by the PACS.

2.1.5.2. Radiographic Phantom. Quality control monitoring of computed radiography performance requires the use of a radiographic test object, or phantom. This phantom is placed in front of a computed radiography imaging plate and cassette and is exposed to a known quantity and quality of radiation. This standardized exposure can then be used to evaluate the performance of the imaging plate, plate scanning apparatus, and image processing algorithms. As a minimum, the phantom should provide an image which can be used to evaluate high contrast spatial resolution, low contrast sensitivity, and signal to noise properties of the computed radiography device. This phantom may also be used to produce a standard image on conventional film, for evaluation of the performance of the film digitizer. The MDIS Program Management Office is currently evaluating a series radiographic test objects specifically developed for evaluating CR performance.[3]

2.1.5.3. Reference Hardcopy Film. In order to calibrate the MDIS film digitizer, a standard film image must be used for digitization. This film should have an incremental gray scale pattern which encompasses the useful optical density range of the digitizer. While it is convenient to use a test film generated by the network laser imager, this practice is not recommended. The scan lines on the laser printed film can interfere with the scan lines of the digitizer and cause interference patterns on the digitized image. In order to avoid this problem, the reference hardcopy film should be produced by direct light exposure of a conventional film.

2.1.5.4. Video Test Pattern Generator. Imaging devices which produce a video signal, such as ultrasound, are interfaced to MDIS through a Video Acquisition Workstation (VAW). A video test pattern generator will be required in order to evaluate the performance of the VAW. These test pattern generators are also useful for isolating the video portion of the image display chain when troubleshooting workstation display problems and for establishing baseline performance during acceptance testing.

2.2 Documentation. Adequate documentation is crucial to a successful quality control program. The information required for the quality control program should be consolidated into a single location, and kept current.

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[3]TOR(CR), TODR(CR), and TO.16, FAXIL, Dept. of Medical Physics, University of Leeds, Leeds LS1 3EX, UK.

2.2.1. Technical Data. Manufacturer's specifications and other technical information must be available for all components of the MDIS system. This information includes maintenance manuals, operation manuals, application manuals, acceptance test reports, and baseline performance data.

2.2.2. Evaluation Procedures. Detailed procedures for obtaining quality control data are the basis of the quality control program. Since QC data is used for trend analysis, it is imperative that the measurements be made in a consistent and reproducible manner. These procedures will be consolidated into a single document which deals with individual MDIS components and with their relationship to other components in the system. A collection of manufacturer's recommendations for quality control of the individual components is not acceptable because it does not address the interdependence of the components. The evaluation procedures and intervals will be subject to refinement as more data is accumulated on equipment performance.

2.2.3. Maintenance Actions and Modifications. The individual in charge of the quality control program must maintain close coordination with maintenance personnel. All scheduled and unscheduled maintenance must be thoroughly documented, and copies of the documentation forwarded to the QC Supervisor. Undocumented maintenance actions can cause abrupt shifts in QC data, and invalidate subsequent trend analysis. Hardware and software changes to sytems interfaced to the PACS, such as CT and MRI, must be carefully monitored and evaluated to ensure they do not impact on the integrity of the interface.

2.3 Program Management Database. A computer database/spreadsheet program is essemtial for recording data, analyzing trends, and producing management reports.

2.3.1. General Description. A digital radiology department is well suited for computerized tracking and analysis of quality control data. In an integrated PACS, such as MDIS, additional efficiency can be gained by maintaining a central database which can be accessed, with appropriate authorization, from PACS workstations throughout the hospital. With such a configuration, QC data can be entered directly into the database at the time it is obtained, using the terminal serving each individual MDIS component.

2.3.2 Test Procedures and Results. A list of the required tests and description of the test procedures for each component can be included as part of the database. Test results can then be input into the database in a "fill in the blanks" format. In this way, consistency of method can be maintained.

2.3.3 Evaluation and Reports. The computer program can be used to perform calculations on the data, analyze trends, and print selected management reports. Results of trend analysis will be used to further refine QC test procedures and intervals. Scheduled maintenance intervals can also be adjusted, based on QC trend analysis.

3. Summary of Quality Control Requirements for MDIS Components. This section contains a listing and some brief descriptions of quality control tests for MDIS components. Detailed quality control procedures will be listed in the MDIS Quality Control Procedures Manual. This is not an all-inclusive list. It is anticipated that other tests will be added as technical documentation of MDIS components is made available.

3.1 MDIS Image Acquisition Devices.

3.1.1. Computed Radiography.

3.1.1.1. Laser Imager Film Density Check. A test pattern image with 16 (AC-1) or 17 (Digiscan) gray scale steps is generated at the CR control panel and printed on a film. The optical density of each of these steps is measured with a densitometer and recorded. This procedure should be performed weekly.

3.1.1.2. CR Phantom Test Image. A standardized exposure of the CR phantoms should be obtained monthly for each type of CR plate in use. High contrast spatial resolution, low contrast sensitivity, image noise characteristics, system exposure sensitivity, and laser beam function will be evaluated for both laser printed film and soft copy display images. Possible designs and test procedures for an MDIS CR phantom are currently being evaluated.

3.1.2. Film Digitizer.

3.1.2.1. Optical Density Calibration. A standardized calibration film is used to check the calibration of the digitizer response and make necessary adjustments. The frequency of this calibration is in accordance with manufacturer's recommendations. The MDIS Program Management Office is currently evaluating a standardized calibration film provided by the digitizer manufacturer.[4]

3.1.2.2. Workstation Evaluation of Digitizer Performance. This test is performed monthly. A standard test film is produced by obtaining an image of the CR test phantom on a high resolution conventional film-screen

[4]Lumisys Inc., Sunnyvale, CA.

system. The film is digitized and the image file brought up on an MDIS workstation. The workstation pixel tool is used to evaluate the phantom image using the same procedures as the CR evaluation.

3.2 Other Image Acquisition Devices.

3.2.1. Digital Interfaces. Most digital imaging devices have the capability to generate a test pattern image. At monthly intervals, this image should be generated at the imaging device and sent across the ACR/NEMA or other digital interface to the MDIS system. Gray scale characteristics and pixel dropout can be evaluated. Phantom images used for quality control of the imaging modality should also be evaluated on the MDIS workstation and compared to evaluations performed on the imaging modality console. These evaluations include tests of image noise, low contrast sensitivity, and high contrast spatial resolution.

3.2.2 Video Acquisition Interfaces. A video test pattern generator will be used to generate a standard image at the input of the frame grabber device. This image will be transferred to the MDIS network and evaluated on a workstation. Phantom images used to measure the performance of the device may also be evaluated on the MDIS workstation.

3.3 Image Output Devices.

3.3.1. Soft Copy Image Display. The output luminance of all workstation monitors will be evaluated on a weekly basis. A standard test pattern image will be used to generate a series of gray scale levels, and the luminance of each level will be recorded. Additional test requirements for soft copy image display devices are currently under evaluation.

3.3.2. Network Laser Printer.

3.3.2.1. Film Density Check. After calibration, a gray scale test pattern image is generated at the imager control panel and printed on a film. The optical density of each of these steps is measured with a densitometer and recorded. This procedure should be performed weekly.

3.3.2.2. Workstation Comparison. A test pattern image will be sent to the network laser printer from an MDIS workstation. The optical density of the hardcopy film will be compared to the equivalent optical density measured from the workstation display. The method described by Lo, et al can be used to determine the equivalent optical density of the monitor.[5]

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[5]Lo SB, Stewart D, Freedman M, and Mun SK, "Display characteristics and display transformation in film and CRT monitor," Proc. 2nd Int. Conf. on Image Management and Communication, pp. 342-347, IEEE Computer Society Press, 1991.

APPENDIX A
LIST OF TECHNICAL PUBLICATIONS

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APPENDIX B
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Acceptance testing design for a large scale PACS installation

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ABSTRACT:

The MDIS acceptance test is the government evaluation of the MDIS system availability, performance and functionality. The test is performed over a period of 30 days and is composed of three test scenarios which are: 1. System/component availability test, 2. Component performance test, and 3. System integration test. A test protocol describes each test in detail, as well as describing the actions of the vendor and test teams during the test period. Fifty six test modules were derived directly from the performance criteria specified in the MDIS contract. These test modules are used by the test team members to evaluate the MDIS system. A database is used to compile the results of the acceptance test for management and comparison of multiple MDIS site results.

1.0. INTRODUCTION

The Medical Diagnostic Imaging Support (MDIS) system is a large Picture Archiving And Communication Systems (PACS) and teleradiology project for U.S Military medical treatment facifities. The first installation of MDIS is at Madigan Army Medical Center at Fort Lewis, Washington. Other Large PACS installations will follow Madigan in close order.[1] The development of an acceptance testing process was required that could provide an in-depth evaluation of each site and yet be flexible enough to be applied to all sites. The Medical Diagnostic Imaging Support (MDIS) Acceptance Test (AT) serves as an evaluation of MDIS phase/system performance and availability, both at the device level and at the integrated system level. It certifies contract compliance and identifies noncompliant areas for remedy. The MDIS program will be installing PACS in three major hospitals in 1992 and 1993. The acceptance test protocol will serve as an evaluation tool, not only for each of the PACS, but for comparison between the PACS and the earlier MDIS Benchmark tests as well.

1.1. MDIS Contract and Bench Mark Test References

The MDIS AT derives its performance criteria directly from the MDIS contract and the vendors proposal. Each of the test requirements is referenced to a specific section of the contract. The formats of the AT protocol and the 56 Test Modules (TM) are derived from the MDIS benchmark tests protocol and the

benchmark evaluators grading book formats. This provides common language , familiar test procedures and patterns, and predictable administrative procedures for the conduct of the test and reporting of test results. Since MDIS PACS sites are installed in phases, acceptance testing will be performed in conjunction with deliveries of each individual MDIS phase. The acceptance test for the final phase at a given facility will be a total system evaluation.

2.0. TEST STRUCTURE

The acceptance test is composed of three separate evaluation processes. The test takes place over a period of thirty consecutive days. The Component Performance Test (CPT) and System Integration Test (SIT) are intended to be completed in ten days, but may require more time if correction of deficiencies is required. The System/Component Availability Test (SCAT) lasts 30 consecutive days. All three parts of the acceptance test can be conducted concurrently. Each of these tests will be described in detail in later sections.

2.1. Test Results and Corrective Action

During the test period there is a daily review of test results between the vendor representative and the evaluation teams. Test results are classified and reported as major or minor deficiencies. Any item of noncompliance with contract specifications <u>which compromises accepted standards of medical practice</u> will be reported as a **Major Deficiency**. Unresolved Major Deficiencies will impact on Phase/System acceptance. Any item of noncompliance with contract specifications <u>which do not compromise accepted standards of medical practice</u> will be reported as a **Minor Deficiency**. Unresolved Minor Deficiencies will be identified at time of acceptance and are to be corrected under warranty.

2.2. System/Component Availability Test (SCAT)

The MDIS contract requires that each system be operational 99% of a 30 day test period and that each component be operational 95% of the same 30 day period. These operational performance criteria are measured by the System/Component Availability Test.

The 99% systems availability will be considered to be satisfied as long as "mission critical" quantities of all components as defined in Table 1 are operational and available for use 99% of the time during the 30 days of the acceptance period. The 95% component availability is considered satisfied as long as each of the components listed in Table 1 are individually operational and available for use 95% of the time during the 30 day acceptance period. Both the 99% and the 95% availability are calculated on 16 consecutive hours per day for 30 consecutive days. Thus the system must provide a minimum of 475.2 hours of usable time and each component must provide a minimum 456 hours of usable time out of the total of 480 hours.

The hospital staff determines which 16 hours each duty are to be used for evaluating system availability. At the Madigan Medical Center, the 16 hour period of the day was from 0600 to 2200 hours. The system remains operational and available for use by the hospital staff during the remaining 8 hours of each day. However, any downtime during this period (2200-0600) is not additive to the 30 day test results.

and the vendor has the option to take equipment down at any time during this period to perform preventative and corrective maintenance as needed. Downtime for maintenance is coordinated with the hospital point of contact to allow for coordination of clinical activities and tracking of maintenance operations.

Table 1. Mission Critical Quantities

Component Name	Critical Quantity	Component Name	Critical Quantity
CR System	4 of 5	SCID-S & SCID-O	5 of 6
Film Digitizer	0 of 1	CT Modality Gateway	1 of 1
DSI Modality Gateway	2 of 3	Modality Interface Unit	2 of 2
Laser Imager/Camera Server	1 of 1	Optical Disk Jukebox	1 of 1
WSU Output Board	7 of 8	20 GB WSU	1 of 1
WSU Input Board	5 of 6	Compressor/Expander	1 of 1
Barcode Printer/Server	4 of 5	Central Host Cluster	1 of 1
Text Printer	4 of 5	RIS Terminal	20 of 21
LAN System, Cabletron	1 of 1		

2.2.1. SCAT Downtime Reporting

In order to maintain accurate records on this test, the following procedures are utilized to record the test results.

Trouble Calls. The hospital staff reports system or component failure by contacting the on-site maintenance staff via the telephone or pager with a complete description of the problem.

Availability Test Log. The vendor maintains a log of all trouble calls. The vendor representative who answers the pager immediately records the problem in the Availability Test Log. He also immediately logs the time of receipt of the trouble call, the name of the reporting individual and his own name. A unique control number is assigned to each trouble call.

Service Reports. The problem is then investigated and resolved. All actions are recorded on a service report. The reports have control numbers which match the control numbers of their respective trouble calls on the Availability Test Log.

Service Report Data. A detailed description of the resolution of the problem is entered on the service report along with the time of resolution, and signed by the originating individual and the designated vendor representative. If the originating individual has gone off shift before the problem is resolved, the new shift supervisor will sign for him. This implies that anyone reporting a problem must brief the oncoming shift supervisor before going off shift. Time required to determine who will sign off on the resolution of the problem will not be counted as downtime. Upon completion, a brief summary of the service report and the time of resolution will be transferred to the Availability Test Log.

2.2 User Errors

Should the vendor team determine that the reported problem was the result of a user error, this finding and the time is immediately recorded on the service report. The vendor representative will then immediately obtain the signature of the originating individual to show agreement with the finding. Should the originating individual not be willing to sign, or disagree with the finding, the vendor representative will immediately seek resolution from the Hospital point of contact. If repair of the equipment is still required, that repair will be made and the time recorded. If the hospital point of contact concurs with the finding of user error, this time will not be counted as down time for either system or component availability.

2.4. Dispute Resolution Team

Should a dispute result regarding any of the above procedures, the vendor representative records that fact and submits the case to the on-site Dispute Resolution Team. This team, consisting of the on-site MDIS Program Management Office representative and the vendor's Site Manager, attempts to resolve the dispute. If successful, they record their findings and and the matter is closed. System downtime and/or component downtime, if any , is logged as agreed to by the Dispute Resolution Team. If the Dispute Resolution Team is unable to resolve the dispute, it is immediately raised to the attention of the vendor MDIS Program Office and the Government MDIS Program Management Office. Should the Government and vendor Program Offices not be able to arrive at a mutually acceptable resolution, the dispute is reported to the MDIS Contracting Officer for final resolution.

2.5. Up/Down Criteria for Major MDIS Components

Descriptions of the criteria which determine whether a major MDIS patient treatment component is up or down for the purpose of the SCAT are included in the test protocol. Each major component's required functionality is briefly listed. Criteria for all components listed in Table 1 are included.

EXAMPLE: CR System Availability. A CR System is considered down if any one of the following system functions is not available: Scan-in Exam ID/Obtain Exam Information from IRIS, Send soft copy to the WSU, Scan-in Plate ID, Perform primary and secondary erasure functions, Read Plate Produce Hard copy at the CR, Perform utility functions.

2.6. Conditions for restart

If the maximum system downtime of 4.8 hours is exceeded before the 30 day period is completed, the test is terminated and restarted at Day 1. Should any component exceed its maximum down time of 24 hours before the end of the 30 day period, the test for that component will be reset to Day 1. Resetting to Day 1 for an individual component test is done without prejudice to the system test. In other words, the system test can proceed when an individual component fails its 95% requirement test. For both the system and the component tests there is a maximum of 90 days allowed for successful completion of the test.

2.7. Distinction between availability and performance

System and component availability is defined as maintenance of the system/component functional operational capability as established on the day that the vendor notifies the government of completion of installation. This does not relieve the vendor of responsibility to meet the component and system performance specifications set forth in the MDIS contract and the vendor proposal. In other words, it is possible for the system or a component to pass the availability requirement for the System/Component Availability Test but fail the Component Performance or System Integration portion of the acceptance test. If any contractual performance specification is not met during the 30 days, it is so noted as a discrepancy to be resolved independent of the 30 day availability test. These types of discrepancies do not constitute cause for stopping the availability test and do not impact the resulting system or component availability evaluation.

2.8. Systems improvements during SCAT

If a major system improvement is developed and verified off-line during the 30 day test, the test may be halted, upon agreement of the vendor and the Government, and the improvement installed and checked out in the PACS system. The test then continues from the point it was halted.

3.0 Component Performance Test (CPT).

3.1 CPT overview

During the CPT period the MDIS component devices are evaluated for basic device-level functionality and performance. Specific thrust questions, contract references, and measurements for CPT evaluation are included in the test modules which pertain to the CPT.

3.2. CPT evaluation requirements

The functionality and performance described in the MDIS contract and the vendor proposal are followed in evaluating MDIS component performance. Additionally, all original equipment manufacturer's (OEM) specifications and acceptance test procedures are subject to inspection at this time. All devices and functionality included in the installation phase are subject to testing. Functionality and performance that

were tested in any previous acceptance tests may be retested to verify that system upgrades have not degraded system performance in other areas.

3.3. CPT test module assessments

The government evaluation teams focus on thrust questions for the following Test Modules (TM's) in the CPT. The thrust questions, specific measurements, and solicitation references associated with each component are listed in the body of the Test Modules. Test are taken from OEM service manuals as well.

Table 2: Test Modules for the Component Performance Test

TM#	Technical Requirement	TM#	Technical Requirement
TM 1	High Performance CR Features	TM 10	SCID-S Hardware Requirements
TM 2	High Performance CR Interface	TM 11	SCID-S Image Manipulations
TM 3	Mid Performance CR Features	TM 12	SCID-S Default Settings
TM 4	Mid Performance CR Interface	TM 13	SCID-S Image Supplements
TM 5	Interface to CT	TM 14	SCID-O Hardware Requirements
TM 6	High Perf Film Digitizer Features	TM 15	SCID-O Image Manipulations
TM 7	High Perf Film Digitizer Interface	TM 16	SCID-O Default Settings
TM 8	Laser Printer Features	TM 17	SCID-O Image Supplements
TM 9	Laser Printer Interface	TM 18	MDIS Image Quality

4.0. Systems Integration Test (SIT).

4.1 SIT overview

A PACS System is much more than the sum of its parts. All parts must work in concert to contribute to hospital functionality. Software design and efficiency must integrate individual component functions into system wide features. The system must also operate at a speed that is conducive to clinical effectiveness. Supporting training, documentation and maintenance services must be in place for continuity of system operations. In the SIT, the overall PACS system is evaluated for basic system functionality, throughput speed, compliance with codes and regulations, and deliverable documentation. Test modules which measure features relating to these characteristic areas are segregated into three testing cycles. These testing cycles allow the test teams to evaluate the system from a perspective different from simple compliance with hardware functions as was done in the Component Performance Test.

4.2 Three Test Cycles for SIT

Over the SIT period two clinical cycles and one administrative cycle are conducted. Each is comprised of groupings of test modules that are related functionally as follows:

a. **Clinical Cycle #1 - Basic System Functionality**

b. **Clinical Cycle #2 - System Throughputs**

c. **Administrative Cycle - Contract Data Requirements List Items**

4.3. Clinical Cycle #1- Basic System Functionality

This cycle assesses functional system performance with special focus on basic system operations. At the start of the test, the government selects system inputs for government evaluation teams to use in assessing system responses and outputs. Actual patient exams, if available may be used instead of mock exams. The government-selected inputs for this cycle are:

a. **New Plain Films.**

b. **Newly Arrived Old Films & Reports.**

c. **New Digital Studies.**

d. **New CR Studies.**

e. **Exam Reports.**

f. **Other Inputs as required.**

4.3.1. SIT evaluation requirements

The MDIS system is tested for the capability to follow the fundamental operating functionality of the diagnostic imaging work flow as described in Figure 1. All aspects of the installation Phase are subject to testing.

4.3.2. Cycle #1 Assessments

The government evaluation team focuses on the following Test Modules in SIT Cycle #1 (See Table 3). Evaluation focuses on the presence and utility of those features, not on the speed at which those features operate. The appropriate thrust questions and contract/proposal references, testing reminders and feature descriptions are included into the body of each Test Module.

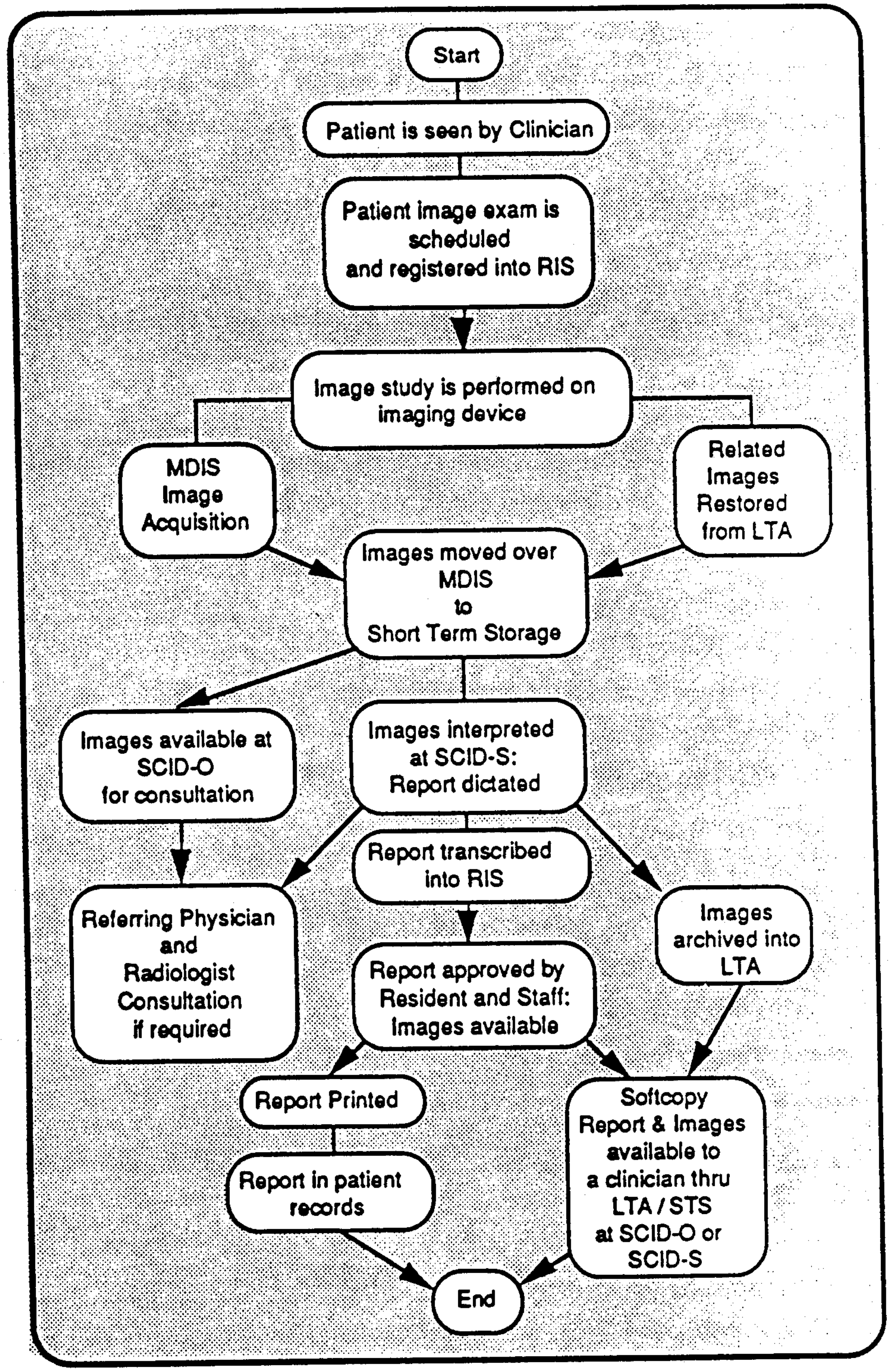

Figure 1: Basic MDIS Diagnostic Imaging Work Flow (filmless operation)

Table 3 Test Modules for the System Integration Test, Clinical Cycle 1

TM#	Technical Requirement	TM#	Technical Requirement
TM 19	Folder Concept Implementation	TM 27	Interim RIS Interface
TM 20	Image Supplements	TM 28	Interim RIS Information Integrity
TM 21	Image Database & Storage Opns	TM 29	Purging Images & Exam Work lists
TM 22	Short Term Storage	TM 30	Loaded Network Performance
TM 23	Long Term Archive	TM 31	Image Transfer to Network
TM 24	Use of Compression	TM 32	Hard Copy Image Production
TM 25	Exam Queries	TM 33	Network Response Ability (untimed)
TM 26	Exam Security	TM 34	Network Reliability After Failure

4.4. Clinical Cycle #2 - System Throughputs

This cycle assesses basic system performance with special emphasis on system timing. Physical measurements are made of the time taken to perform system operations under loaded and unloaded conditions.

4.4.1. Cycle #2 Inputs

All preloaded images and patient information available in clinical cycle #1 must be available at the start of this cycle. For network throughput testing, four pre-loaded image sets are utilized with the parameters shown in Table 4.

Table 4: Standard Image Sets for Image Throughput Testing

Image Type	Data Set per Image	Compression Type	Images/Study
New Chest	2K x 2.5K x 10 bits	bit preserving	2
Previous Chest Image	"	10:1	4
New CT Study	512 x 512 x 12 bits	bit preserving	50
Previous CT Study	"	bit preserving	50

4.4.2. Cycle #2 Assessments

The government evaluation team focuses on system performance measurements and evaluates it using the Test Modules in Table 5. These measurements are performed at both low and high system loading periods. Maximum degradation of performance due to system loading is specified and tested for compliance.

Table 5: Test Modules for the System Integration Test, Clinical Cycle 2

TM#	Technical Requirement	TM#	Technical Requirement
TM 35	Image Transfer from Acq Devices	TM 42	Display Speed from STS to SCID-O
TM 36	Throughput Time	TM 41	Display Speed from LTA to SCID-O
TM 37	Display Speed at SCID-S	TM 40	Display Speed at SCID-O
TM 38	Display Speed from LTA to SCID-S	TM 39	Display Speed from STS to SCID-S

4.5. Administrative Cycle Assessments

The government evaluation tests of the non-clinical aspects of the system are performed during the SIT Administrative Cycle. Many of the items inspected are referenced in the contract as Contract Data Requirement List (CDRL) items. These items are individually specified in the MDIS contract in great detail and are individually accounted for when measuring vendor compliance. These tests require physical inspection of a wide variety of equipment and documents as well as the interviewing of several functional area supervisors such as the Fire marshal and the facilities engineer.

Table 6 Test Modules for the System Integration Test, Administrative Cycle

TM#	Technical Requirement	TM#	Technical Requirement
TM 43	Facilities/Installation Compliance	TM 50	CDRL AF Installation Plan
TM 44	Operator Training	TM 51	CDRL AG - Quality Control Plan
TM 45	CDRL AA - As Built Drawings	TM 52	CDRL AH - Software Tutorial
TM 46	CDRL AB - Special Tools And TMDE	TM 53	CDRL AJ - Training Plan
TM 47	CDRL AC - Master parts List	TM 54	CDRL AK - List of Supplies
TM 48	CDRL AD - List Of Spare Parts	TM 55	CDRL AL - Data Schedule
TM 49	CDRL AE - O & M Data	TM 56	CDRL AM - Security Plan

5.0 Results reporting

The results are compiled on a daily basis and reported to the MDIS Project Office and to the Vendor. Upon completion of the test a preliminary report is provided to the MDIS Program Manager, the vendor and the contracting office. A final report is due within ten days of completion of testing.

5.1. Test Result Database

A database has been created to track the findings of the acceptance test. The recorded test results from each test module are keyed into the database. Each test module routinely has several individual test results to be recorded. Thus, the number of database records far exceeds the number of test modules. The tracking of each deficiency noted during an acceptance test is required to ensure that the vendor has ultimately complied with the terms of the contract. The process of inspecting, reporting, discussing, and negotiating corrective actions for deficiencies may be long and tortuous. Assignment of unique database records to each deficiency establishes a point of reference for all follow on actions as well as tracking and reporting status of the deficiencies. The record assigns a unique number to the finding and provides fields for the following data items: a. Deficiency log number, b. Status, c. Test module reference, d. Deficiency description, e. Corrective action and point of contact, f. Resolution date, g. Administrative comments, h. Contract specification reference number.

5.2. Management and Comparative Analysis

The intended use of the database is as a management tool which allows for recording and tracking of deficiencies identified during the acceptance test process. Additional benefits include comparative analysis of findings from of the MDIS PACS sites being installed. This comparative analysis may serve to point out strengths and weaknesses in the contract specifications, OEM components, sub-contractor performance, vendor's engineering or management capabilities, and government testing methods.

6.0. Conclusions

Large scale PACS systems are of such size and complexity that a multi-faceted, and yet logically structured, procedure must be utilized for acceptance testing. The design of the MDIS acceptance test process includes specific procedures to determine the contract compliance of a large-scale PACS by performing successive evaluations of the system, each with a different focus. The test process focuses on the system in terms of reliability, component performance, functionality, throughput, support services and deliverable documentation. The close relationship between the MDIS Benchmark tests, MDIS contract specifications, Acceptance Test Protocol, Acceptance Test Modules, and the Test Result Database will enable the MDIS Program Management Office to measure, evaluate, report, and manage the contract compliance of installations of large-scale PACS in multiple facilities.

7.0. References

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Teleradiology: Exploiting Its Promise to Create the Virtual Radiology Department

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ABSTRACT:

The Virtual Radiology Department is the Department of Defense (DoD) solution to optimizing functionality, availability, performance, reliability, and cost management for a fielded teleradiology system. Teleradiology (T/R) serves merely as a technology connectivity environment defining the various hardware, software and communication building blocks. Within this environment the Virtual Radiology Department exploits the capabilities of the various building blocks making time and distance barriers irrelevant. A technology core at the hub supports the spoke imaging requirements. The hub "sees" the spokes as merely extensions of the Virtual Radiology Department. The spokes act as if they are part of the hub. As a result of efficiencies presented by the Virtual Radiology Department concept, the DoD is creating the first one in the Republic of South Korea (ROK) under the auspices of the AKAMAI Project.

1.0. INTRODUCTION

The MDIS System is a large Picture Archiving and Communications System (PACS) and T/R project for DoD medical treatment facilities (MTF). In September 1991 a four-year contract for MDIS was awarded to Loral Aerospace Corporation, Loral Western Development Laboratories, San Jose, California, and Siemens Gammasonics, Inc., (SGI) Hoffman Estates, Illinois.

1.1 Current Sites.

DoD MTFs which now have MDIS include Madigan AMC, Fort Lewis, Tacoma, Washington; US Air

Force Medical Center Wright-Patterson Air Force Base (AFB), Dayton, Ohio; and Brooke AMC, Fort Sam Houston, San Antonio, Texas. There are T/R systems linking the 410th Medical Group (MG), K.I. Sawyer AFB, Skandia, Michigan to Wright-Patterson AFB. A T/R system whose hub is the 58th MG, Luke AFB, Phoenix, Arizona, is linked to the 836th MG Davis-Monthan AFB, Tucson, Arizona, and awaits linkage to six more spokes. The Veteran's Administration Hospital, Baltimore, Maryland, has an MDIS system in place. Loral and SGI have also put this technology in place at Hammersmith Hospital London, United Kingdom, and are actively pursuing proliferation of MDIS at other private sector healthcare institutions in the United States, Europe, and Asia. For a significant number of reasons, the ROK offered an opportunity to install T/R in a unique configuration. This unique configuration coalesced as a result of the clinical scenario, workload, practice patterns, distance and time constraints, and isolation both real and cultural.

1.2. T/R Specifications

In general, the basic T/R capability required for the MDIS System is receipt and transmission of associated clinically significant information (e.g., radiology reports, patient data, and images) to and from the facility reading the images and the facility imaging the patients.

The specific purpose of T/R spelled out in the MDIS Performance Work Statement (PWS) is to provide primary image interpretation capability for radiological images acquired at medical treatment facilities without assigned radiologists. This concept allows for central reading of digitized images, by radiologists staffed at medical treatment facilities (hubs), transmitted via dedicated communications links from spoke medical treatment facilities. As many as eight spokes can be expected to be serviced by a single hub with a fully implemented inter-MTF network. A regional approach to fielding this technology accommodates images from any Department of Defense healthcare facility through distributing workload electronically. In addition to these inter-MTF communications links, the MDIS PWS requires a system for local access to MDIS via voice-grade phone lines. This capability is included to support portable teleradiology. Portable here is defined as equipment readily moveable from one location to another by the operator. This definition is in contrast to equipment movement requiring engineering accommodation and specific technical equipment removal and installation skill.

2.0 THE VIRTUAL RADIOLOGY DEPARTMENT

The Virtual Radiology Department is a systemic approach to exploiting T/R in solving failures in timeliness of and accessibility to diagnostic reporting for radiology images. It is different from simple T/R. T/R sees the hub/spoke relationship as parasitic. The Virtual Radiology Department recognizes that the hub/spoke relationship is best optimized by exploiting hub/spoke synergy.

2.1. Conventional T/R

T/R relies on image generation at a remote imaging site (spoke) with one-way image transmission to a central location (hub) for diagnosis and reporting.

Image generation. The remote site may generate digital images for transmission from computed radiography (CR), direct digital output (e.g., Magnetic Resonance Imaging (MRI), Computed Tomography (CT), Ultrasound (US), charge coupled device (CCD) etc.), film digitization, or frame grab (e.g., older US). Once the image is in digital form in the system it is transmitted to the imaging hub.

Image transmission. Images are moved from the spoke to the hub by local area networks (e.g., Thick/thin ethernet, etc.) or conventional communication methods in a wide area network configuration (e.g., copper cable, microwave, satellite/earth station, fiber optic cable, etc.). Images enter the communication system through various gateways using Modulator/De-modulators (MODEMS), Digital Signal Processors (DSP), etc.

Image display for diagnosis and reporting. The imaging hub displays the image on a soft copy image display (SCID) workstation and/or prints the image to film for diagnosis and reporting. Reports are telephoned back to the spoke, transmitted by facsimile (FAX) machine, or, in some cases, generated digitally and transmitted electronically word-processor to word-processor.

Image archive. Images at the remote site are archived differently depending on the type of image. Hard copy x-ray film may be simply filed. Images captured by frame grab or direct digital may be archived to magnetic video or computer tape. They may also be archived to conventional magnetic media such as floppy disks or Winchester hard drives. In technologically mature T/R configurations archiving may occur to compact disk-read only memory (CD-ROM). Further, images may be archived at the spoke or hub or both.

2.2 Virtual Radiology Department

The Virtual Radiology Department combines image capture at the spoke as well as the hub with two-way image transmission to and from the hub and spoke for diagnosis, reporting and to the maximum extent possible archiving at the hub. The system architecture also creates connectivity among remote imaging sites and other hubs directly and/or through the main hub. In communication architecture terms it works like a combination of star, bus and ring topology.

Operational Considerations. Virtual Radiology Department functionality is not substantially different from T/R. Image generation, transmission, display for diagnosis and reporting, and archiving are not significantly different. .

Two-way communication. The most noteworthy difference between T/R and the Virtual Radiology Department is that digital images, patient demographic data and reports flow through the system to and from all the hubs and spokes. Operationally, the digital data is accessible throughout the system without regard to specific location, distance or time. This important feature provides the capability to conduct on-line/real-time provider consultations. From a simple phone

call to elaborate teleconferencing, attending and/or admitting health care providers can be linked long distance with radiologists and consultant specialists. The on-line/real-time communication link compliments the improved image availability resulting from creating the digital network in making accurate patient assessments and diagnosis. Further, with teleconferencing capability patients at hubs or spokes can be "seen" by health care providers throughout the network who are on-line. This teleconferencing capability extends the Virtual Radiology Department directly out to the patient.

Continuing Medical Education (CME). This connectivity also enriches continuing medical education access and activity for health care providers. Connected electronically with colleagues by the image network (with or without phones and/or teleconferencing,) they can conduct near "hands-on" educational experiences. Digitized images from teaching files in the central archive can be recalled by any provider, anywhere, anytime. They can read the image report, any annotations on template layers on the actual image, and compare images from several sources such as a CT, conventional radiography and MRI for a single patient's complaint or among patients with similar diagnosis. Access to the patient demographics and image management database permits them to select and sort on classes of patients, images or any other database field. They can then cue up the image sets they've selected and conduct comparison studies for learning.

Image Archiving. The hub is, to the maximum extent possible, the sole repository of digital imaging data. This requirement makes the Virtual Radiology Department substantively different from T/R. The central archive, in what is essentially a wide area network (WAN), achieves major economies of scale, improves archival reliability, and reduces proliferation expense.

Service. Maintenance, system management and training staff can be centrally located at the hub. The bulk of the technically sophisticated equipment (e.g., digital archive, file server and back plain, high resolution, multi-screen SCID workstations and sophisticated digital image generation devices such as MRI, CT, US, CR, etc. and the VAX database manager are for the most part located at the referring hub. The hub is also where most, and in some cases all, of the network's radiologists are located. The Virtual Radiology Department saves the expense of numerous large, technically complex archives and file servers as well as manpower costs associated with maintaining all technical aspects of the system.

Reliability and Maintainability. In order to insure image availability from the central archive an image sourcing strategy was necessary. For small, low image volume MTFs where x-ray film continues to be the image capture medium of choice, they can rely on film as their back-up. If communications are interrupted or their film digitizer fails or the hub is off-line, they can transfer the film by surface or air transportation to the hub for definitive diagnosis and reporting. For MTF's relying on CR or other direct digital image capture modes, they will have a sufficiently large intermediate magnetic disk archive to

store several days worth of images. They can download this digital information to floppy disk, removable/transportable hard drives, or print the images to x-ray film for transport to the hub in the event a formal diagnosis cannot wait. Once the image is on floppy disk, removable/transportable hard drive or x-ray film conventional surface or air transportation methods can be used.

Because of their technical complexity, archives and file servers require high quality periodic maintenance (PM). A single archive location greatly improves opportunities to conduct PM to prevent failures. It also reduces downtime if a system fails since staff is present or on-call geographically nearby.

With simpler system configurations at the spokes, the T/R equipment, facility and utility infrastructure needed to support it is greatly simplified. This simplification is important in light of severe space limitations, severely restricted funds availability to build and/or modify space, and utility systems operating at or near capacity. This simplicity multiplies across the spokes in cost savings for system acquisition, building modification and utility installation and expense.

By selecting dial-up, fractal MODEMs, communications expenses are also minimized. Communication charges are based on actual time the link is in use for the level of band-width specified. Essentially, it works like your long distance telephone service. What you use is what you buy.

3.0 THE AKAMAI PROJECT

AKAMAI, in the Hawaiian language, means "clever" or "smart" or "the best" of something. The AKAMAI project is the DoD project for proliferation of T/R and PACS in the Pacific theater. The Pacific Command extends from Madagascar to Hawaii and from just south of the Arctic Circle to just north of the Tropic of Capricorn. This area is roughly 51 percent of the earth's surface. Because of the scope of the project it is divided up into smaller manageable projects.

Project Daybreak — The Republic of South Korea and Malaysia

Project Sunrise — Mainland Japan, Okinawa and Guam

Project New Dawn — Alaska and Hawaii

3.1. Project Daybreak.

Project Daybreak is a three phase project to proliferate the Virtual Radiology Department concept in the ROK. These phases were selected based on greatest need for improved access to diagnostic imaging information as well as improved patient care.

Phase I. Phase I extends to medical sites on Kunsan and Osan (SongTan) Air Bases ; Camps Casey (Tongduchon), Walker (Taegu) and Humphries (Pyongtaek) ROK, connected to a hub at the 121st Medical Evacuation (MEDEVAC) Hospital, YongSan, ROK; with communication to Tripler Army Medical Center (TAMC) and the University of Hawaii (UH) Honolulu, Hawaii, massive parallel-processor super computer center in Kihei, Maui, Hawaii and on to Georgetown University Medical Center (GUM), Washington, District of Columbia (DC).

Phase II. Included in Phase II is connectivity through the National Aeronautics and Space Administration (NASA) Advanced Communication Technology Satellite (ACTS) to GUM with connectivity through the University of Hawaii's super computer. This consortium of private sector academic and healthcare and federal sector healthcare and communication agencies provides the capability to conduct intensive research into all areas of T/R operations and functionality. The collaboration also accommodates opportunities to strive toward new features for digital imaging and remote diagnosis such as computer aided and enhanced diagnosis. It also creates an environment for pure research into methodologies to improve digital imaging technology, the quality of health care and reduce health care costs. These reductions could grow out of improved health care provider productivity, lower morbidity and diseases recidivism, and decreased length of hospital stay resulting from more widespread availability of timely and accurate diagnostic detail. These reduced costs should contribute to greater patient access to health care earlier in the course of their illness and better prospects for maintaining their health and, when ill, quicker recoveries.

Phase III and Beyond. Subsequent phases will extend spokes throughout the South Korean peninsula creating a network of 16 US armed forces medical treatment facilities (MTFs) and links to Japan, Hawaii, and the more of the mainland US. These links will parallel the aeromedical evacuation route permitting seamless movement of patients and their diagnostic information along the aeromedical route.

3.2. Other projects.

Projects Sunrise and New Dawn, also under the umbrella of the AKAMAI project, are only in the planning stages. However, lessons learned in Project Daybreak will contribute directly to their success.

4.0. THE ROK

In the early planning stages, and even following on-site visits to the ROK, no one accurately foresaw the numerous limiting factors in attempting to proliferate T/R in its traditional configuration. Issues of unexpected complexity include acquisition and long term maintainability expenses, time and distance, infrastructure and utility system support, and real and cultural isolation.

4.1. ROK Scenario

On the South Korean peninsula, an area the size of Indiana (roughly 38,230 square miles), nearly 36,000 active duty military men and women in the US Air Force, Army and Navy are totally dependent on three radiologists for their diagnostic needs. Similar situations exist in Alaska, Guam, Honshu and Okinawa islands, Japan, Singapore, Madagascar, on board Navy ships, and for military personnel deployed on humanitarian missions in Thailand, Somalia and other remote areas. US military forces have a significant presence in the Pacific region. They represent a massive healthcare workload on

widely dispersed military sites across an area covering approximately 103 million square miles and including more than 316,000 authorized beneficiaries.

4.2. Fielded Virtual Radiology Department Configuration.

The final outcome of full and accurate assessment of the ROK scenario as well as a new understanding of the building blocks of T/R is the ROK Virtual Radiology Department. It is complex in its conceptualization yet simple in its application.

The Hub. The hub is the 121st MEDEVAC Hospital, YongSan near Seoul. The hub has the central CD-ROM archive in an optical disk jukebox (ODJ) as well as the Working Storage Unit (WSU) file server and back plain, and the VAX where the database resides. It also has the gateway off the peninsula to TAMC, through UH, and eventually NASA's ACTS to GUM. Further, it provides PACS capability within the 121st MEDEVAC.

The Spokes. The spokes are each slightly different:

51st Medical Group Osan Air Base. Osan is a relatively new facility with a spacious computer room and adequate space for workstations in patient care areas. The radiology department is easily and inexpensively adaptable. They also have a radiologist on staff. Because of their support capability their spoke is designed as a "filmless" environment. They will have several days of magnetic disk back-up on site to provide capability in the event of communication loss to or failure of the hub. The Osan radiologist will diagnose and report on images from within the facility as well as Kunsan and Camp Humphries.

8th Medical Group Kunsan Air Base. Kunsan, another spoke, will capture images on film and digitize them. Film serves as their back-up. Due to space limitations, the age of their building, low workload, and stressed utilities with little excess capacity they will have only two SCID workstations. These SCID workstations will be used daily by the staff along with film. Additionally, specialists (e.g., orthopedics, cardiologist) will "circuit ride" from Osan to provide specialty care on-site and will rely on these workstations to bring their consultant images from the 121st MEDEVAC archive.

43rd Mobile Army Surgical Hospital (MASH) Camp Humphries. Camp Humphries will simply deliver film to Osan to be digitized. This delivery is instead of driving several hours to YongSan in Seoul as they do now. Diagnostic reports will flow back from Osan on the same land shuttle bringing the x-ray films for digitization.

543rd Medical Detachment Camp Walker and Troop Medical Clinic Camp Casey. Camps Walker and Casey will look very much like Kunsan. They will digitize film. However, because of greater workload and better space and utility availability they will have additional workstations. A future spoke at the 125th Medical Detachment, Camp Red Cloud may include filmless capability.

Communication. Each phase I spoke is connected to the hub by dedicated T-1 communication lines. These lines were already in-place and available and created only a small additional expense for their use. The

importance of this fact is that the speed with which images are transmitted throughout the system greatly increases the perception that it is all one radiology department. Further, high speed communication permits the "on-line, real-time" consultant capability so critical to providing a standard of care comparable to what one could expect in any major city in the United States.

5.0 CONCLUSION

T/R, when proliferated at peak efficiency, is not a universal "cookie cutter" solution to time, distance, isolation, access, timeliness and other limitations of current film based systems. T/R, representing digital imaging technology building blocks, does provide a framework for efficient, effective proliferation. The concept of the Virtual Radiology Department takes this premise and pushes the technology to the cutting edge by placing these T/R building blocks in a configuration that most closely resembles an intra-MTF PACS but is, in reality, an inter-MTF T/R system. As additional systems are fielded in the Pacific as part of the AKAMAI project, the additional knowledge gained will let us experience and assess whether the Virtual Radiology Department does in fact efficiently and effectively overcome many of the limiting factors conventional T/R simply does not address.

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The Future in Healthcare: A Bibliography

While the Department of Defense "Virtual Radiology Department" in the Republic of Korea is an innovative approach to providing diagnostic health care in a geographically remote and medically underserved area it is just a glimmer on the horizon of bright opportunities the future holds for us. This bibliography represents a sampling of articles and presentations from the current literature on some of the technologies likely to have major impacts on diagnostic, palliative, curative, preventive and rehabilitative care. This bibliography is not intended to be a definitive information resource, for there are most certainly other sources and more information available. However, this list should serve as a stepping off point for the reader interested in beginning their investigations into the future course of healthcare.

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